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Cost-effectiveness of Passing Lanes: Safety, Level of Service, and Cost Factors

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Abstract: This study has resulted in: (a) a methodology for analyzing the level of service and safety of passing lane options; (b) economic feasibility and cost-effectiveness methods based on level of service improvement, reduction of delay, increased safety, and cost of providing a passing lane; (c) a procedure for comparative analysis of climbing and passing lane options; and (d) a practical, user-friendly microcomputer-based tool for the evaluation of passing lanes, as well as climbing lane options.

Existing warrants for the provision of passing lanes were reviewed. Methodology was developed for analyzing the operational performance and safety of two lane highway sections, with and without passing lanes. The functions developed for estimating the level of service factors (i.e., platooning, average speed) were validated with field data. Research in the operational performance and safety of climbing lanes has already been reported in the Research and Development report, TDS-90-08.

The methodology for the study of cost-effectiveness of passing lanes was implemented in the form of a user-friendly microcomputer program. This program also incorporates the methodology for the study of climbing lane options for priority analysis of passing lane/climbing lane solutions on two lane rural roads. The use of cost-effectiveness methodology and the microcomputer program are illustrated.

Comments: The final report of Research and Development Project 21215. User's manual (TDS-91-03) and Programmer's Manual (TDS-91-04) for PCL computer program also available.

Key Words: Passing lanes, climbing lanes, two-lane road, highway, cost, level of service, model, cost-effectiveness, safety, truck, heavy vehicle.

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EXECUTIVE SUMMARY

Passing and climbing lanes on existing two-lane rural highways, although costly, provide cost-effective means for improving both traffic operations and safety problems. Such problems are attributed to platooning and low average operating speeds as compared to speed desired by most road users. Increasing traffic volume and the presence of slow moving vehicles on two lane highways result in:

- limited opportunities for safe passing manoeuvers,
- increased platooning,
- a drop in average speed, and
- increased safety hazards.

It has become recognized through research and operational experience that the passing and climbing lane solutions are appropriate for roads with low and medium traffic volumes which normally do not warrant four lane cross sections, and also for routes with high seasonal demand. Passing lanes for level and rolling terrain and climbing lanes for road sections upgrade, in addition to providing an immediate improvement of operational performance and safety, become a part of the an ultimate four lane cross section. Due to methodological deficiencies, the cost-effectiveness of these auxiliary lanes have not been analyzed extensively.

Although passing and climbing lanes are both auxiliary lanes provided for improving passing opportunities on two lane highways, there are differences in the operational analysis and design of these two companion strategies. As a result of a previous study funded by the MTO, a methodology for the cost-effectiveness analysis of climbing lanes has become available. The main attributes of the climbing lane methodology are the study of truck warrants, design of climbing lane, level of service estimation, cost-effectiveness and economic feasibility analyses.

This study was initiated to overcome methodological deficiencies in the analysis and evaluation of passing lanes and in priority analysis involving both passing and climbing lanes. Specifically this study has:

- developed a methodology for analyzing the operational performance and safety of passing lane options,
- developed an economic feasibility and cost-effectiveness methodology for the evaluation of passing lanes,

- defined a procedure for comparative analysis of climbing and passing lane options (if relevant for highway sections under study),
- implemented the above methodologies in the form of a practical, user-friendly microcomputer-based tool for the evaluation of passing as well as climbing lane options.

The initial step in this study was the examination of existing criteria (warrants) for the provision of passing lanes. Specifically, the existing Ministry of Transportation of Ontario (MTO) passing lane criteria, based on safe passing opportunities, was incorporated in this study for reference purposes.

The next step required the definition of an approach to analyze the operational performance of two lane highway sections with and without passing lanes. Due to the absence of guidelines and procedures for the estimation of level of service of two lane highway sections containing auxiliary lanes, new techniques had to be developed. Given the absence of data on traffic and geometric design characteristics of a large number of sites "without passing lane" and "with passing lane", such data were generated through a specifically designed method based on the random selection of such characteristics.

The study approach called for the use of a microscopic simulation model to investigate platooning, average speed, spot speed and other performance indicators of such sites. Two available microscopic simulation models, namely TWOPAS and TRRAR were evaluated in terms of data needs and outputs. The TWOPAS model development was sponsored by the Federal Highway Administration (FHWA), U.S.A. The TRRAR model was developed by the Australian Road Research Board. For reasons of model capabilities and familiarity with the program outputs, the TWOPAS model was used in this research to simulate a large number of two lane sections (sites).

For the development of equations (models) that would enable the estimation of level of service indicators, traffic and geometric design data in association with outputs of the TWOPAS model were used. The level of service measures incorporated in the study include "percent of vehicles in platoons" and "average speed". While both indicators were utilized for the estimation of level of service, the "percent of vehicles in platoons" could not be used directly to quantify delay reduction due to passing lanes. The average speed was used for the purpose of estimating travel time saving benefits.

A large number of regression equations (macrosimulation models) were developed for average speed and percent of vehicles in platoons covering variations in terrain type and restrictions

on overtaking. Two sets of equations were developed in response to the assumptions of low platooning and high platooning at the entrance to the simulated highway sections.

The regression equations were validated through a comparison of their outputs with field data collected from selected sites on Highway 17. Field investigations measured spot speeds at the beginning and end of study sites through the use of radar meters. Video tapes were used for observing platooning, average speed, traffic volume, directional split and composition of traffic. Estimates of platooning and average speed obtained from the equations compare favourably with field data.

The development of a safety model which could be used for predicting accident reduction attributable to improvement of operational performance due to the presence of a passing lane was the next step. In a previous study on climbing lanes, an accident prediction model was developed which related safety to changes in average speed. The basic information that was used as a basis for the accident involvement estimation equation was collected for level, rolling as well as upgrade sections of two lane highways. For an estimated improvement in average speed, the model enables the prediction of a reduction in accident involvement rate. The validity of the safety model was investigated by comparing its results against known data as well as findings of other studies. The results were favourable.

Following a large number of simulations, guidelines were developed for passing lane length and its effective distance downstream. Also, for reference purposes, the MTO procedure for estimating lane frequency (i.e., distance between passing lanes) was incorporated in the methodology.

The development of the methodology for the estimation of level of service was undertaken next. The approach is based on the estimation of percent time delay and average speed (obtained from regression equations) and the level of service criteria contained in the 1985 edition of the Highway Capacity Manual (HCM).

Methodology for cost-effectiveness and economic feasibility analyses was structured to be flexible for the evaluation of passing lane options and for sensitivity testing purposes. The effects of changes in traffic volume and other factors could be studied with ease. The cost-effectiveness technique enables the investigation of effectiveness measures individually (against cost) or an overall measure of effectiveness (based on delay reduction and safety improvement) could be viewed against cost. The methodology is designed to enable an investigation of economic feasibility (both with and without discounting of benefits).

The algorithm for the development of a microcomputer program incorporated the methodological framework and constituent techniques. The program also combines the following:

- new methodology specifically developed for the cost-effectiveness of passing lanes,
- the cost-effectiveness of climbing lanes (CECL), and
- the MTO passing lane criteria, based on safe assured passing opportunity.

In total, the overall methodology developed in this study as well as in the previously completed study on climbing lanes, verified against field data, and operationalized as a "user friendly" microcomputer program, incorporates all factors that affect the cost-effectiveness of passing and climbing lanes. The use of the methodology is illustrated in the form of selected example applications.

The microcomputer program, namely "Cost Effectiveness of Passing/Climbing Lanes" or called PCL, has been designed to be user-friendly. The modular nature of the program offers much flexibility for applying various modules. This new program incorporates all the features of the "Cost Effectiveness of Climbing Lanes" or CECL program. Major components of the program include: site and traffic characteristics, the climbing lane part of the program (incorporating all functions of CECL), performance of passing lanes including checking warrants and level of service estimation, and cost-effectiveness studies.

The program was tested in the form of a comparison between manual computations and PCL computer program outputs. The example application was designed to check the logic and computational routines of the PCL program and also to illustrate the use of methodology for analyzing and evaluating passing lane/climbing lane projects.

The methodology was tested in the form of numerous sensitivity analyses, case studies of individual sections of two lane highways, and one extended section containing five sites that are candidates for passing or climbing lane installations. Results obtained appear to be logical and reasonable.

A number of conclusions and recommendations are presented in the report. Highlights are reported here.

- Percent of vehicles in platoons is a more sensitive measure of level of service than spot or average speed.

- The operational effectiveness of passing lane is highly sensitive to traffic volume and control on overtaking (i.e., the extent of "no passing zones"). In level or rolling

terrain, the percentage of trucks and percentage of recreational vehicles have about the same effect on platooning of traffic. However, there are small differences between these two types of road users. In a number of cases, trucks have a higher effect on platooning than recreational vehicles (RVs) on two lane roads without a passing lane. On the other hand, on level and rolling terrain, RVs appear to have a higher effect on speed and platooning for road sections with a passing lane.

- Although longer passing lanes have a somewhat higher effect on the reduction of platooning and improving speed than shorter lanes, in economic efficiency terms, the best length of a passing lane is between 1 and 2 km.

- Passing lanes improve traffic flow in terms of reducing platooning and improving speed for a considerable distance downstream from the start of such lanes. The effective distance of a passing lane depends upon traffic volume level. Even for low traffic volume levels, the effect of a passing lane becomes negligible beyond 13-16 kms from the start of such lanes.

- The report provides suggestions on passing lane length and effective distance for various traffic levels.

- The provision of passing lanes has improved safety of two lane highway sections.

- The level of service criteria contained in the Highway Capacity Manual (1985) applicable to upgrade sections (specific grades) have not been harmonized with those for level/rolling terrain analysis. Consequently, the level of service outputs for a climbing lane analysis will differ from those for a passing lane analysis for the same site. However, the results of cost-effectiveness analysis and economic feasibility are not affected by the level of service criteria.

The flexibility offered by the modular nature of the microcomputer program should be an asset for expedient and comprehensive analysis and evaluation of passing as well as climbing lane options. The methodologies developed in this as well as the previous study and the microcomputer program are recommended for practical use by the profession for priority analysis of passing lane/climbing lane solutions on two lane highways.

Future research in new measures of operational performance of two lane highways and in the refinement of the accident rate prediction equation would enhance the utility of the methodology and is, therefore, recommended.

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The opinions expressed are those of the authors. They do not necessarily reflect the views of MTO or of Carleton University.

Chapter 1

INTRODUCTION

1.1 Background

As compared to widening a two lane highway into a four lane cross section, passing and climbing lanes fall in the category of low cost solutions to improving traffic operations and safety. These auxiliary lanes, if properly planned, can be regarded as cost-effective means for improving both traffic operations and safety. Research and operational experience suggests that such options are appropriate for roads with low to medium traffic volumes which may not warrant four lane cross sections and also for routes with high seasonal peaking of demand such as recreational travel.

A general definition of a passing lane is that it is an added lane, provided in one or both directions of travel, for improving passing opportunities. In this respect, climbing lanes for road sections on grade that meet warrants and passing lanes for level or rolling terrain fall under the same definition. There are, however, differences in operational analysis and design of these two companion strategies for alleviating problems of platooning and safety on two lane roads.

Given the high cost of passing lanes (i.e., typically between one-half to one million dollars), it is essential that design and investment decisions are based on realistic operational, safety and cost analyses. A methodology for assessing the cost-effectiveness of design and investment options, including a comparative analysis of climbing and passing lane options (if relevant for highway sections under study) is needed.

Planning for the provision of auxiliary lanes (i.e., passing lanes, climbing lanes) over extended length of a rural two lane road requires the identification of potential sites and the length of lanes. Warrants for climbing lanes (based on critical length of grade, level of service changes) and guidelines for passing lanes (based on the assured passing opportunities) have been used for developing options.

The location and length of passing lanes are to be defined for further study. Factors that are to be included in the evaluation of options include operational effectiveness, safety and cost. For the analysis and evaluation of passing lanes, there is a need to assess their effect on the quality of traffic flow and safety of operations. Following such analyses, the cost-

effectiveness of options have to be assessed for decision-making.

For sections of roads where climbing lane options are also under consideration, comparative evaluations of both types of auxiliary lanes may be desired.

Previous research funded by the MTO involved a review of truck climbing lane criteria, and the development of a microcomputer-based methodology for the evaluation of delay and safety aspects of climbing lane options on two lane rural roads [1,2,3,4]. The methodology serves as an aid to decision-making for climbing lanes. Until the initiation of this study, such a methodology was not available for passing lanes.

Given that both passing lanes and climbing lanes serve the function of reducing the "percent time delay" and thus improving the level of service on two-lane roads by enhancing the opportunities to break up platoons, it was appropriate to develop methodology for evaluating the effectiveness of passing lanes. Furthermore, it is considered desirable to create the flexibility in decision-analysis by enabling the comparative examination of the cost-effectiveness of passing as well as climbing lane options.

1.2 Research Objectives and Scope

The objectives of this research are:

1. to develop a methodology for analyzing the operational performance and safety of passing lane options,

2. to develop a cost-effectiveness methodology for the evaluation of passing lanes,

3. to develop a practical, user-friendly microcomputer-based tool for the evaluation of passing lane options, and to enable a comparative evaluation of passing as well as climbing lane options, if relevant.

As for scope, this study has focussed on passing lane aspects of the overall capacity and level of service of two lane highways. The project was limited to the development of a microcomputer-based methodology for determining, on the basis of cost-effectiveness analysis, the relative merits of design length and location of passing lanes. Also, it enables a comparative examination of results for passing lane options (obtained from the new methodology developed) with those of a climbing lane options (estimated from the climbing lane part of the program).

The end result is a coherent, objective tool which enables the exploration of both sets of options, namely passing and climbing lanes for solving two lane highway problems.

For the quantification of safety attributes of passing lanes, reliance has been placed on available information. The broader question of safety of two lane roads or truck-related safety issues is beyond the scope of this research.

1.3 Report Organization

Chapter 2 describes the overall research framework. Study specifications and the resulting research approach are described.

Factors for defining passing lane options are covered in Chapter 3. Design considerations are described as well.

Techniques for the estimation of platooning, speed, level of service and delay are reported in Chapter 4. New methodology developed for estimation of these factors is described.

Chapter 5 is devoted to the subject of safety of two lane highway sections, with and without passing lanes. The development of a method to quantify safety impacts is reported.

Chapter 6 covers the process of verifying models developed in this study for the estimation of operational performance of two lane highways with and without passing lanes. The process and results of checks made on the outputs of models against field data are described.

Chapter 7 presents the theoretical aspects of the cost-effectiveness methodology for assessing the merits of passing lanes and for applicable sites, comparisons between passing and climbing lane options.

Chapter 8 reports the algorithm for the microcomputer program. Also, example applications are provided. Results of manual computations and computer program outputs are compared.

Conclusions and recommendations are presented in Chapter 9. Following Chapter 9, references used in this study are listed. Appendix A contains selected results of sensitivity analysis.

Chapter 2

RESEARCH FRAMEWORK

2.1 Methodological Deficiencies

In general, two lane highway capacity and level of service subjects have received insufficient research attention. Specifically, the effects of passing and climbing lanes on the operation of two lane rural highways have not been investigated to a satisfactory extent. For example, the 1985 Highway Capacity Manual does not offer guidelines or techniques for the analysis of passing or climbing lanes [5].

Over the years the limited research work that has taken place in Canada, U.S.A. and Australia, can be categorized as:

. guidelines for installation of passing lanes,
. design length of passing lanes,
. location/frequency of passing lanes,
. safety of passing lanes, and
. operational effectiveness of passing lanes.

Canadian research on passing lanes started in early 1970s in the form of developing guidelines for the provision of passing lanes [6,7]. Studies carried out in Ontario and Alberta defined criteria for climbing provision in terms of a balance between the demand for passing and the supply of passing opportunities [8]. In 1975, the Ontario Ministry of Transportation and Communications established criteria for passing lanes, based on the consideration of a percent of highway length with "assured passing opportunities" [6,7]. Due to the assumptions made in the development of the methodology and its weak theoretical basis, its results could be used only for reference purposes.

The Australian research on the provision of criteria for passing lanes has produced minimum traffic volume guidelines for passing lanes [9,10]. The most recent studies on the criteria for passing lanes were carried out in the U.S.A. See references 11 to 17. These and other investigations, particularly those sponsored by the Federal Highway Administration (FHWA), took a broader approach by relating the frequency of passing lane provision to operational effects on platooning and safety [17,18].

Design length of passing lanes has received some research attention. Attempts have been made to relate length of passing lanes to one-way flow rates -- the range being 0.8 km to 3.2 km., although the use of 1.6 km appears to be favoured even for traffic levels higher than 700 veh/direction of travel [15,16].

The role of economics in establishing the design length of passing lanes is also recognized. More recent thinking on the subject of length of lane is to establish the requirements for passing distance based on passenger car-passing a truck and a truck-passing another truck. The passing models mostly in use are based on the car-passing another car [19].

Research on safety of passing lanes has uncovered that passing lanes reduce accident rates as compared to those applicable to two lane highway sections without such lanes [15,16,20-23].

Operational analysis of two lane highways have been based mostly on microscopic simulation models [15,24,25]. For practical and expedient applications, macrosimulation models were not available at the time of initiating this research. In order to overcome this deficiency, such models were developed in this study.

As noted above, a capacity and level of service analysis procedure for two lane highways with passing lanes does not exist. There is a need to relate time delay and other measures of effectiveness with volume, traffic composition, geometrics and availability of passing opportunities. The development of macroscopic models of two lane highway sections for relating upstream traffic characteristics and highway characteristics for predicting the operational effectiveness would be desirable. There is need to improve the scientific basis for investigation of the operational and cost-effectiveness of passing lanes.

Also, there is a need to integrate the two sets of cost-effectiveness procedures, one for the assessment of climbing lanes and the other for passing lanes, at the level of comparative evaluations. A coherent objective tool is required for exploring both sets of options (i.e., passing lane and climbing lane) for solving two lane highway problems cheaper than full four laning.

2.2 Study Specifications

This research required:

- the development of a cost-effectiveness model structure for evaluating combinations of passing lane length and the effective length of road influenced by the presence of the passing lane (the effective length would include the length of the passing lane itself and the down stream section of two-lane highway with improved platooning),

- development of methods for estimating delay (i.e., percent time delay, actual delay) and providing broad indicators of safety for passing lane options,

. field studies yielding data for testing models, and

. development of a microcomputer-based tool for the cost-effectiveness evaluation of proposed passing lane solutions on two lane highways.

2.3 Research Approach

2.3.1 Priority Criteria

For establishing relative desirability of auxiliary lane projects, consisting of passing lanes and climbing lanes, criteria related to improvements in safety and operational performance are relevant. Furthermore, considering the cost of such projects, it is logical to establish priorities on the basis of cost-effectiveness and economic feasibility. Further elaborations of this theme are contained throughout this report as well as a previous report on the cost-effectiveness of climbing lanes [2]. An example of priority analysis is provided in Chapter 8 of this report.

2.3.2 The Cost-Effectiveness Methodology

An integration of passing and climbing lane methodologies is suggested in Figure 2.1. The overall study framework is shown in Figure 2.2.

For extended lengths of two lane roads in rolling or hilly terrain, the designer may have options for improving platooning that include passing and climbing lanes. It would be appropriate to build flexibility in the methodology for comparing the relative effectiveness of such options. Such flexibility should be useful for decision making where climbing lane warrants and cost-effectiveness answers are not very convincing and the designer may wish to consider relative merits of proving a climbing lane on grade or a passing lane up stream where costs may be more favourable. Furthermore, the same site could be analyzed by using the climbing lane as well as passing lane methodologies.

It should be noted that while the methodology for passing lane analysis and evaluation (proposed here) differs from that of climbing lane, the indicators of effectiveness and cost-effectiveness (i.e., delay reduction, safety) are the same for both cases. Consequently, it would be appropriate to assess relative merits of options based on passing and climbing lane type of road improvements.

The overall research framework consisted of the following steps (Figure 2.2):

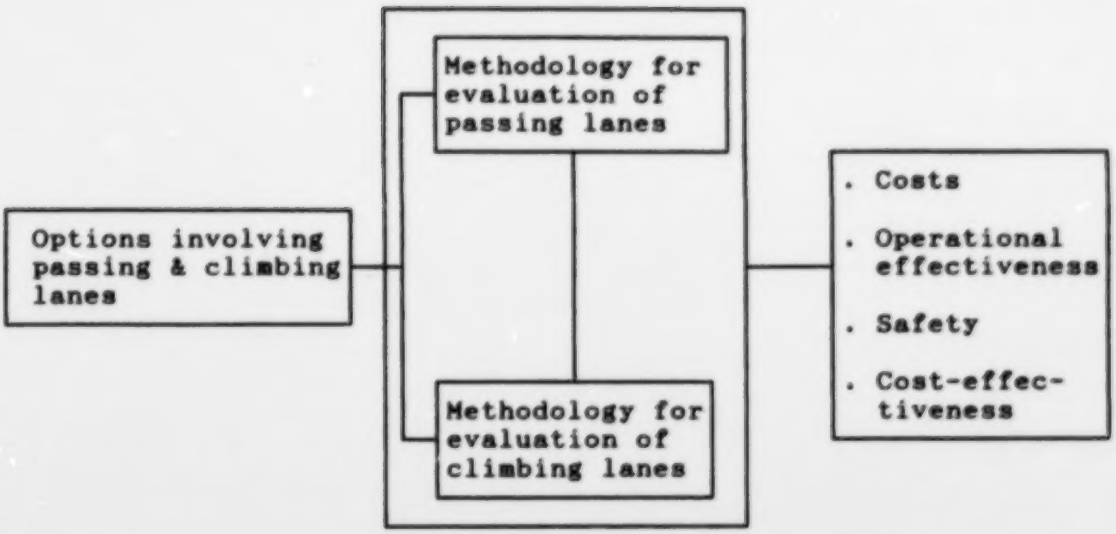


Figure 2.1: The Concept of Integrating Passing and Climbing Lane Evaluation Methodologies

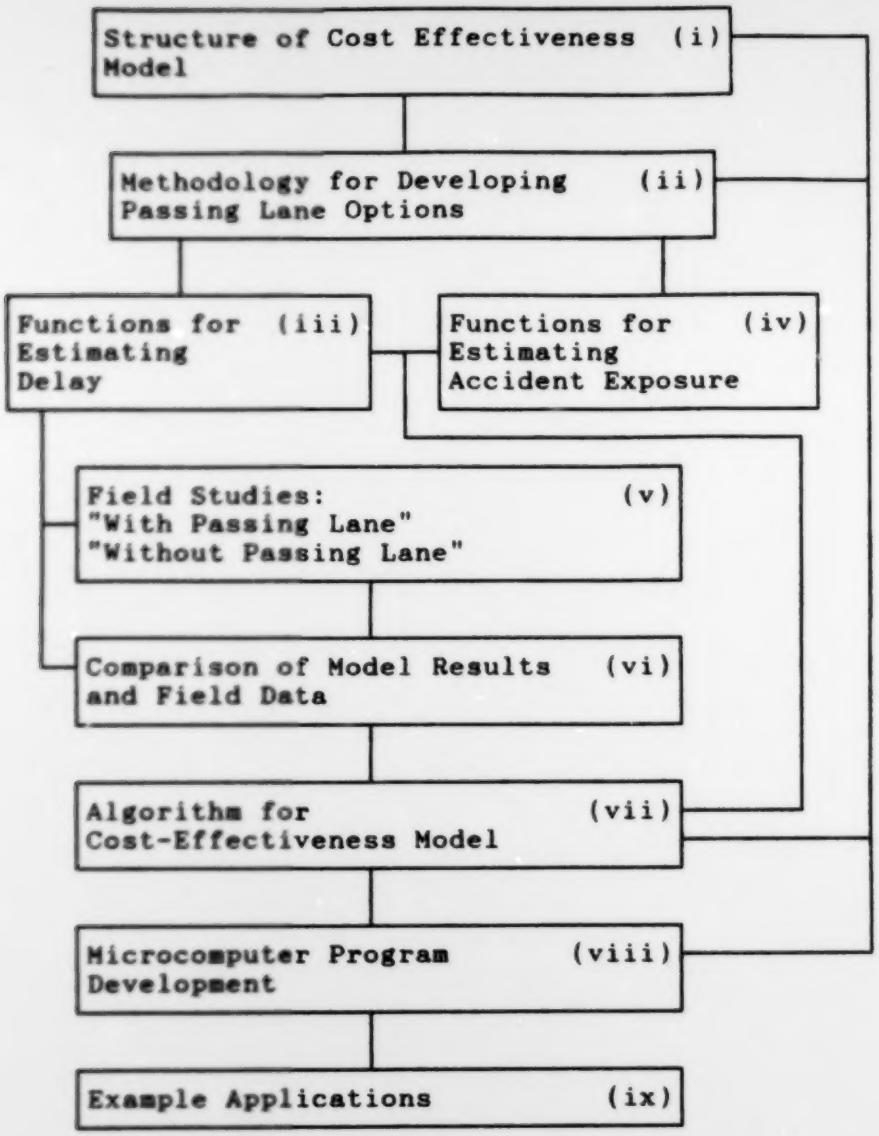

Structure of Cost Effectiveness Model (i)
Methodology for Developing Passing Lane Options (ii)
Functions for Estimating Delay (iii)
Functions for Estimating Accident Exposure (iv)
Field Studies: "With Passing Lane" "Without Passing Lane" (v)
Comparison of Model Results and Field Data (vi)
Algorithm for Cost-Effectiveness Model (vii)
Microcomputer Program Development (viii)
Example Applications (ix)

Figure 2.2: Study Framework

(a) definition of passing lane configurations -- combinations of passing lane itself and the length of road influenced by the presence of the lane (i.e., the effective length),

(b) estimation of effectiveness: definition of measures of effectiveness (% time delay, delay reduction, safety improvement),

(c) passing lane cost estimation, and

(d) cost-effectiveness assessment.

The components of the framework are briefly described in this chapter. Detailes and illustrations are provided in chapters 3 to 8 of this report.

2.3.3 Techniques for Developing Passing Lane Options

Methods were studied for establishing or characterizing passing lane options, using the following variables:

. length of passing lane,
. location of passing lane in association with effective length of the lane.

New guidelines were defined for identifying candidate locations for passing lane provision. Also, the existing MTO criteria were used for reference purposes.

2.3.4 Estimators of Platooning, Average Speed, Level of Service and Delay

Models were developed for estimating operational performance of options. Percent of vehicles in platoons and average speed were related to road and traffic variables in the form of predictive equations for passing lane effectiveness.

To maximize realism and usefulness in application, all determinants of operational performance were applied to the extent feasible. Models were defined according to logical categories of information needs (e.g., models applicable to highway sections with passing lanes as opposed to those without such lanes).

Variables that were investigated for the study of operational performance include: length of passing lane, effective length of lane, traffic volume, directional split, and traffic composition. Simulation runs were required for obtaining the operational performance values for options to be tested. A microscopic simulation model, namely TWPOPAS, was used.

2.3.5 Estimators of Safety

Safety is an important consideration in the provision of passing lanes. On the basis of available information, the safety effectiveness of passing lanes were investigated. A method was developed for estimating safety levels associated with passing lane options with known (estimated) operational performance.

2.3.6 Field Studies

Sites were identified "with passing lanes" and "without passing lanes" for field studies. At these sites, spot speed and platooning were measured. Speed readings and spot platooning were observed at the approach and downstream. Radar meters were used for speed studies and video cameras enabled the observation of platooning, average speed, traffic composition and directional split. A time headway of 5 seconds or less was used for defining vehicles in platoons.

The output of the performance models were compared with the field data. Inputs to the model were the characteristics of the site and traffic at that site. Also other independent checks were made on the reliability of model results.

2.3.7 Algorithm for Cost-Effectiveness Model

A detailed algorithm was developed for the entire cost-effectiveness model, including the flexibility to compare the operational and safety effectiveness of passing lane options with climbing lane options. The program was intended to display the effectiveness of a given option. Also, it was planned to assess relative effectiveness of a number of alternatives. The economic feasibility evaluation of passing lanes (in net saving/benefit terms) was desired as well.

2.3.8 Development of Microcomputer Program

The cost-effectiveness model was implemented as a user-friendly micro-computer program, consisting of sub-programs or modules:

Module A: Input: roadway and traffic characteristics:
- . length of road section under study, passing/no passing features of road, terrain,
- . traffic volume (DHV,AADT), % trucks, % RVs, directional split.

Module B: Check on grades for establishing whether to use passing lane or climbing lane methodology

Module C: Definition of desired percent of assured passing

opportunity & comparison with assured passing opportunity (based on existing MTO criteria for passing lane provision)

Module D: Use of cost-effectiveness of climbing lane methodology

Module E: Input passing lane information (i.e., length, location) by using suggested values to be provided or by using MTO's existing methodology

Module F: Estimate performance:
- Delay and other indicators of level of service without and with passing lane
- Safety exposure (accident involvement rate or safety index) without and with passing lane

Module G: Comparison of travel time and accidents for with & without passing lane cases

Module H: Develop effectiveness measures for each alternative:
- effectiveness based on single and multiple measures

Module I: Cost of passing lane:
User specified in terms of construction and maintenance costs

Module J: Estimate economic feasibility of each alternative by comparing savings and costs

Module K: Develop cost-effectiveness values for each alternative and display results,
- Comparison of alternatives for a given site
- Comparison of alternatives for different sites
- Comparison of passing lane with climbing lane option (if relevant)

Module L: Comparison of passing and climbing lane analyses (manual)

2.3.9 Example Applications

This final part of the research framework was intended to illustrate the use of the microcomputer-based methodology by showing example applications.

Chapter 3

PASSING LANE OPTIONS: METHODOLOGICAL CONSIDERATIONS

3.1 Generation of Passing Lane Options

Passing lanes are considered as a low cost measure to improve operational efficiency and safety of extended sections of two lane highways as opposed to widening the highway to four lanes at only a limited number spots. A passing lane is an auxiliary lane provided in one or both directions of travel for improving passing opportunities [15]. As most two lane highways are already built, passing lanes could be added as a part of safety and operational improvement programs. From a long term perspective, passing lanes (provided on level or rolling terrain parts of the highway) and climbing lanes (installed on upgrade sections), could become a part of the multilane cross section.

Climbing lanes are generally regarded as passing lanes. However, a passing lane in level/rolling terrain cannot serve the function of a truck climbing lane. The location and length of a climbing lane is highly site-specific, being dependent upon upgrade, length of grade and design truck [1]. The location and length of a passing lane in level or rolling terrain can be is arrived at through considerations of operational efficiency, safety and cost.

In the planning and design of auxiliary lanes, the distinction between passing lanes and climbing lanes is important. In the evaluation of a climbing lane, the prime consideration is to improve traffic operations at upgrade sites to at least the same service quality as adjacent sections of the highway. This implies that traffic in the upgrade direction is the prime consideration. This objective is reflected in climbing lane warrants/criteria.

On the other hand, for passing improvements, the evaluation methodology should consider operational improvements (i.e., enhancing passing opportunities) for an extended length of the highway. Logically, for sites with low grades, an auxiliary lane could serve the function of improving passing opportunities and service level for the upgrade section as well as some distance beyond, provided that the site is situated where passing opportunities have to be enhanced.

It should be stressed that the location of a passing lane can be varied and the selection of a proper location is an important design consideration [15,16].

There are no rigid warrants for passing lanes. Guidelines or criteria reported, in most instances relate to safe passing opportunities and level of service. According to MTO's existing guidelines, passing lanes are similar to climbing lanes, although not necessarily installed on upgrades and that these are applied to two lane highways that serve large volumes of slow moving vehicles (e.g., recreational routes). A reference is almost always made to safety enhancement as a consideration, although no formal warrants are specified [23].

The MTO's existing guidelines for the location and frequency of passing lanes rely upon the estimation of desired passing opportunities (that could become available through a passing lane) and checking assured passing opportunities available without a passing lane. The methodology for establishing location and frequency of passing lanes is discussed further in Chapter 7. Applications of new methodology are provided in Chapter 8.

3.2 Design Features

Passing lanes could be constructed in a systematic fashion at generally regular intervals. An overall plan for auxiliary lanes could incorporate the climbing and passing lanes and could be based on priority analysis as illustrated in this report (See Chapter 8).

Configurations of passing lanes could vary, depending upon local needs. Construction costs are a consideration, but cannot be viewed in isolation from the effectiveness part of the equation. The driver should be given advance information about the location of a passing lane through advance signs. Also, the passing lane location should be obvious to the driver [15,16].

If passing and climbing lane functions could be combined at one site, it would be highly desirable. On the other, provision of passing lanes at locations of high platooning on level or rolling terrain may offer a more cost-effective solution than to build one at a non-optimal site with a marginal grade.

Decisions on passing lane location should take into account the requirement for adequate sight distance at lane addition and lane drop tapers.

Separated passing lanes (as opposed to adjoining passing lanes) are preferred since these will not give the driver the impression of a four lane highway.

The desirability of using one passing lane by both opposing directions of traffic has been under study from a safety perspective. As elaborated in Chapter 5, on the basis of some site analyses, it was concluded that for low traffic levels

(e.g., AADT of less than 3000), opposing traffic may be allowed to use the widened section of the highway.

Details on the length and spacing of passing lanes are provided in Chapters 4 and 8. Information on climbing lane length and location is reported in a previous study report funded by the Ministry of Transportation, Ontario [2].

Chapter 4

ESTIMATION OF PERFORMANCE: PLATOONING, SPEED, LEVEL OF SERVICE AND DELAY

4.1 Level of Service

As previously noted, available design manuals and general literature do not offer methodology for estimating the level of service implication of providing passing lanes on two lane highways. A major effort was mounted in this research to overcome this deficiency. In addition to the methodology for estimating level of service, it was a requirement of this research to quantify in dollar terms the benefits to road users due to the improvement of flow and safety of two lane highways attributable to passing lanes.

From a theoretical perspective, there are a number of indicators of levels of service that could considered for the quantification of operational efficiency [26,27,28]. Some of these are:

- percent of vehicles in platoons and platoon size,
- assured safe passing opportunities offered by highway sections for given traffic levels,
- passing rate over a section of a highway, and
- percentage passing opportunities (the ratio of the actual passing rate to the desired passing rate) (passings/veh-km).

The 1985 HCM procedures for the analysis of level of service of two lane highways use the following measures [5]:

- percentage of travel time spent delayed -- being in platoons behind other vehicles,
- average travel speed, and
- capacity utilization.

In this research the first two indicators of the level of service were used. The approach followed for the development the models that enable the quantification of these measures for two lane highways without and with passing lanes is covered in this chapter.

4.2 Performance Measures

The HCM (1985) provides guidelines and techniques for the assessment of level of service on two lane roads without passing lanes. In the absence of corresponding means for establishing the level of service of two lane highways with passing lanes, it was

decided to develop new methodology for this purpose. The choice of performance measures was guided by requirements of practical application considerations and compatibility with the level of service criteria provided in the HCM (1985).

The Highway Capacity Manual (1985) recognizes that the "percent of time delayed" would be a better indicator of driver-perceived quality of service. However, it is difficult to observe directly in the field and to develop its functions for level of service analyses. Consequently, a measure related to percent time delay, namely percent of vehicles in platoons, was chosen for the quantification of level of service. Field measurements would be possible by observing the percent of vehicles travelling at headways less than 5 seconds (i.e., 4 seconds or less) [5].

The average travel speed was chosen as well since it enables the assessment of level of service and also it could be used to quantify travel time savings (regarded as a benefit). Additionally, changes in average speed could be used as variable to estimate a reduction in accident involvement rate.

As for the application of the above noted measures, the percent time delay ranges are specified by the HCM (1985) for the categorization of various levels of services. The corresponding average speed ranges are provided as well. In this study both measures are used and level of service answers are displayed.

In the absence of available techniques for operationalizing the platooning and average speed measures for two lane highways, it became necessary to develop equations for this purpose. The use of a microsimulation model for the analysis of each passing lane problem was not regarded to practical.

4.3 Simulation of Highway Performance: The Approach

The use of a microsimulation model was considered to be necessary, given the absence of means to observe numerous sections of two lane highway for long periods of time. A microsimulation model, namely TWOPAS model, was selected for simulating the performance of large number of two lane highway sections that are considered to represent level and rolling terrain. The level terrain implies grades less than 1.5% and rolling terrain is represented by grades more than 1.5% but less than 2.5%.

The choice of variables for simulating the performance of two lane sections, and ultimately for the development of regression models was based on causal relationships. The variables used are:

- terrain (level, rolling),
- length of road section (considered to be effective distance of passing lane, if present),
- traffic volume,
- directional split (percent of traffic in the advancing direction),
- percent trucks (number of trucks),
- percent recreational vehicles (RVs) (or number of RVs),
- length of passing lane (if applicable), and
- overtaking allowed/not allowed.

4.4 Selection of Microscopic Simulation Model

Two available microscopic simulation models were evaluated for use in this study. The TWOPAS model, developed by the Midwest Research Institute for the Federal Highway Administration (FHWA) (U.S.A.), simulates traffic operations on two lane highways (with or without auxiliary lanes) by reviewing position, speed, and acceleration/deceleration of each vehicle and advances vehicles on the roadway [24]. The TRRAR (Traffic on Rural Roads) model, developed by the Australian Road Research Board, operates basically on the same principle as that of the TWOPAS model [25]. The TWOPAS is implemented on a mainframe computer whereas the TRRAR is available for use on a microcomputer.

The microsimulation models can accommodate a large number of vehicle types. Up to 18 vehicle types can be simulated by TRRAR and 13 vehicle types by TWOPAS. The TWOPAS model permits the specification of average approach speed. The distribution of speeds for each category of vehicles is represented according to a truncated normal probability density function. In relative terms, the TWOPAS model has more outputs than TRRAR, such as overall speed histograms, time margins and aborts, and headway and platooning summary. A comparison of the two models based on similar inputs can be found in Table 4.9 of reference 2. On the basis of model capabilities, familiarity with program outputs and experience with its use, the TWOPAS model was chosen for use in this study.

The TWOPAS model enables detailed simulation of traffic operations, based on user specified traffic and roadway characteristics such as overtaking restrictions, presence of auxiliary lanes, horizontal and vertical curvature or variables that influence sight distance. The model calls for the specification of vehicle population and vehicle characteristics relevant to the application environment such as power and weight characteristics or driver characteristics. Traffic factors that can be specified include volume, speed, directional split, etc. Numerous outputs are available.Those of interest in this study include spot speed, average speed, the number of overtakings and measures of platooning. Further detail of the TWOPAS models and

its inputs for Ontario conditions, the reader may wish to refer to Chapter 4 of reference 2.

As for the use of microsimulation models in general and the TWOPAS model in particular, it might be of interest to note that an earlier version of this model was used extensively for the development of functions contained in the two lane rural highway chapter of the HCM (1985).

4.5 Development of Macroscopic (Regression) Models

Given the absence of information on a large number of sites on two lane highways that are with and without passing lanes and lack of required input information, an approach was developed for random selection of roadway and traffic features. For each variable of interest, a realistic set of values were defined (e.g., DHV values ranging from 100 to 1500 vehicles/hour). Upon advice from the Statistical Consultation Centre, Carleton University, a random selection procedure was adopted for developing information base for case sites. These site-specific information items were used as inputs to the TWOPAS model.

Two levels of platooning at the entrance to simulated sections were specified in order to observe answers in response to input platooning environment. The results of microsimulation obtained from TWOPAS model are the performance indicators of the simulated sites. In the case of highway sections with passing lanes, the passing lane was located at the outset of the simulated section. The model outputs covered the entire section up to the end of the effective distance. In all cases, only one passing lane was provided in the advancing direction.

The macrosimulation (regression) models developed relate the inputs to the Twopas model (i.e., road and traffic data) with the operational performance variables. The road and traffic data were used as independent variables and the results of the TWOPAS model were used as the dependent variables. The data were classified according to terrain, overtaking allowed/not allowed, high platooning/low platooning at the entrance to the road section and the presence/absence of a passing lane. The regression equations are given in the following section.

4.6 Macrosimulation Models

Two sets of equations were developed for the estimation of "percent of vehicles in platoons" (at the end of a highway section -- extending to the end of effective distance) and average speed (for the two-way flow) over the effective distance. Set one is based on the assumption of low platooning at the entrance to the section of the road under study. The second set reflects the high platooning assumption.

Both sets of equations are to be used and the average speed is to be found. "Percent of vehicles in platoons" is used as an indicator of "percent of time vehicles are delayed".

For highways with design speed of less than 100 km/h, average speeds estimated through the use of equation should be reduced by about 6.5 km/h. The average speeds that correspond to various levels of service are to be adjusted accordingly.

4.6.1 Estimation of Platoons/Extent of Time Delay (Advancing Direction)

Two Lane Road Without A Passing Lane

Equation NLPA: Level Terrain, No Passing Lane, Passing Allowed, Low Platooning

% in platoons (direction 1) = - 102.014122 + 0.024746 (two way volume in veh/h) + 0.026848 (direction 1 or advancing volume in veh/h) + 0.378681 (% trucks) + 0.206237 (%RVs) + 12.578612 (Ln effective distance in m)

R^2 = 0.9130
N = 34

Equation NLPAH: Level Terrain, No Passing Lane, Passing Allowed, High Platooning

% in platoons (direction 1) = - 10.480817 + 0.037307 (two way volume in veh/h) + 0.284969 (% of volume in direction 1) + 0.227858 (% trucks) + 0.454073 (% RVs) + 1.429404 (Ln effective distance in m)

R^2 = 0.8857
N = 34

Equation NRPA: Rolling Terrain, No Passing Lane, Passing Allowed, Low Platooning

% in platoons (direction 1) = - 62.690983 + 0.025444 (two way volume in veh/h) + 0.029595 (direction 1 volume in veh/h) + 0.380196(% trucks) + 0.17973 (%RVs) + 7.992368 (Ln effective distance in m)

R^2 = 0.9207
N = 34

Equation NRPAH: Rolling Terrain, No Passing Lane, Passing Allowed, High Platooning

% in platoons (direction 1) = - 87.052802 + 0.02161 (two way volume in veh/h) + 0.032339 (direction 1 volume in veh/h) + 0.233653 (% trucks) + 0.143488 (% RVs) + 11.553606 (Ln effective distance in m)

R^2 = 0.84
N= 34

Equation NLPNA: Level Terrain, No Passing Lane, Passing Not Allowed, Low Platooning

% in platoons (direction 1) = - 81.551649 + 0.037318(direction 1 volume in veh/h) + 0.081991 (% trucks) + 0.128426 (%RVs) + 14.088428 (Ln effective distance in m)

R^2 = 0.84
N = 34

Equation NLPNAH: Level Terrain, No Passing lane, Passing Not Allowed, High Platooning

% in platoons (direction 1) = 8.163308 + 0.019053 (two way volume in veh/h) + 0.321224 (% of volume in direction 1) + 0.01887 (% trucks) + 0.270193 (% RVs) + 2.884911 (Ln effective distance in m)

R^2 = 0.82
N = 33

Equation NRPNA: Rolling Terrain, No Passing Lane, Passing Not Allowed, Low Platooning

% in platoons (direction 1) = - 82.847073 + 0.040381 (direction 1 volume in veh/h) + 0.090593 (% trucks) + 0.071261 (%RVs) + 13.94845 (Ln effective distance in m)

R^2 = 0.84
N = 34

Equation NRPNAH: Rolling Terrain, No Passing Lane, Passing Not Allowed, High Platooning

% in platoons (direction 1) = - 28.843311 + 0.001243 (two way volume in veh/h) + 0.036295 (direction 1 volume in veh/h) + 0.028029 (% trucks) + 0.157512 (% RVs) + 8.453287 (Ln effective distance in m)

R^2 = 0.77
N = 34

Two Lane Road With A Passing Lane

Equation LPA: Level Terrain, Passing Lane, Passing Allowed, Low Platooning

% in platoons = - 73.23469 + 0.025085 (two way volume) + 0.030024 (direction 1 volume) + 0.348983 (% trucks) + 0.308168 (% RVs) + 11.424936 (Ln effective distance in m) - 2.997049 (Ln passing lane length in m)

R^2 = 0.91
N = 34

Equation LPAH: Level Terrain, Passing Lane, Passing Allowed, High Platooning

% in platoons = -28.842058 + 0.021544 (two way volume ni veh/h) + 0.036077 (direction 1 volume in veh/h) + 0.261604 (% trucks) + 0.307007 (% Rvs) + 5.745285 (Ln effective distance in m)- 1.667636 (Ln passing lane length in m)

R^2 = 0.90
N = 34

Equation RPA: Rolling Terrain, Passing Lane, Passing Allowed, Low Platooning

% in platoons = -77.36628 + 0.022924 (two way volume in veh/h) + 0.033262 (direction 1 volume in veh/h) + 0.239016 (% trucks) + 0.282086 (% RVs) + 11.164687 (Ln effective distance in m)- 1.92239 (Ln passing lane length in m)

R^2 = 0.88
N = 34

Equation RPAH: Rolling Terrain, Passing Lane, Passing Allowed, High Platooning

% in platoons = - 73.292148 + 0.011917 (two way volume in veh/hr) + 0.040657 (direction 1 volume in veh/h) + 0.151112 (% trucks) + 0.574558 (% RVs) + 9.946509 (Ln effective distance in m)- 0.590872 (Ln passing lane length in m)

R^2 = 0.89
N = 34

Equation LPNA: Level Terrain, Passing Lane, Passing Not Allowed, Low Platooning

% in platoons = - 120.028193 + 0.04222 (direction 1 volume in veh/h) + 0.211367 (% trucks) + 0.344354 (% RVs) + 20.382657 (Ln effective distance in m) - 4.357488 (Ln passing lane length in m)

R^2 = 0.84
N = 34

Equation LPNAH: Level Terrain, Passing Lane, Passing Not Allowed, High Platooning

% in platoons = - 35.948194 + 0.008345 (two way volume in veh/h) + 0.034955 (direction 1 volume in veh/h) + 0.180449 (% trucks) + 0.30797 (% RVs) + 12.871598 (Ln effective distance in m)- 6.490118 (Ln passing lane length in m)

R^2 = 0.83
N = 34

Equation RPNA: Rolling Terrain, Passing Lane, Passing Not Allowed, Low Platooning

% in platoons = - 142.999622 + 0.045393 (direction 1 volume) + 0.190076 (% trucks) + 0.184176 (% RVs) + 22.992976 (Ln effective distance in m) - 4.49706 (passing lane length in m)

R^2 = 0.83
N = 34

Equation RPNAH: Rolling Terrain, Passing Lane, Passing Not Allowed, High Platooning

% in platoons = - 72.035217 + 0.006596 (two way volume in veh/h) + 0.040743 (direction 1 volume in veh/h) + 0.205168 (% trucks) + 0.247202 (% RVs) + 16.637101 (Ln effective distance in m)- 6.726374 (Ln passing lane length in m)

R^2 = 0.82
N = 34

4.6.2 Estimation of Combined Average Speed for Both Directions

Two Lane Highway Without A Passing Lane

Equation NLPA (Combined Average Speed for Both Directions): Level Terrain, No Passing Lane, Passing Allowed, Low Platooning

Average speed (combined for both directions) in km/h =
123.886651 - 0.009677 (Two way volume in veh/h)
- 0.00216 (Opposing volume in veh/h) - 0.083272 (% Trucks)
- 0.109698 (% RVs) - 2.671846 (Ln effective length of road in m)
R^2 = 0.97
N = 34

Equation NLPAH (Average Speed): No Passing Lane, Level Terrain, Passing Allowed, High Platooning

Direction 1 Average Speed (km/h) =
98.391769 - 0.005723 (Two way volume in veh/h)
- 0.005691 (direction 1 volume in veh/h) - 0.064222 (% Trucks)
- 0.112523 (% RVs) - 0.320888 (Ln effective length of road in m)

R^2 = 0.94
N = 34

Direction 2 Average Speed (km/h) =
111.446213 - 0.006447 (Two way volume in veh/h)
- 0.00997 (Opposing volume in veh/h) - 0.051152 (% Trucks)
- 0.043947 (% RV) - 1.573644 (Ln effective length of road in m)

R^2 = 0.82
N = 34

Find speed for direction 1 and direction 2 and then calculate weighted average according to direction split of traffic.

Equation NRPA: Rolling Terrain, No Passing Lane, Passing Allowed, Low Platooning

Combined average speed (km/h) = 119.19015 - 0.00955 (two way volume in veh/h) - 0.003032 (opposing volume in veh/h) - 0.097291 (% trucks) - 0.106647 (% RVs) - 2.145238 (Ln effective distance in m)

R^2 = 0.98
N = 34

Equation NRPAH: Rolling Terrain, No Passing lane, Passing Allowed, High Platooning

Average speed in direction 1 (km/h) = 98.29172 - 0.004508 (two way volume in veh/h) - 0.007125 (direction 1 volume in veh/h)- 0.082 (% trucks) - 0.147167 (% RVs) - 0.267737 (Ln effective distance in m)

R^2 = 0.90
N = 34

Average speed in direction 2 (km/h) = 128.659178 - 0.005013 (two way volume in veh/h) - 0.009801 (opposing volume in veh/h)- 0.069548 (% trucks) - 0.118309 (% RVs) - 3.457779 (Ln effective distance in m)

R^2 = 0.82
N = 34

Equation NLPNA (Combined Average Speed): No Passing Lane, Level Terrain, Passing Not Allowed, Low Platooning

Average speed (combined for both directions) in km/h = 120.621472 - 0.006958 (Two way volume) - 0.001579 (Opposing volume ni veh/h) - 0.019674 (% Trucks) - 0.087345 (% RVs)- 3.114566 (Ln effective length of road in m)

R^2 = 0.95
N = 34

Equation NLPNAH: No Passing Lane, Level Terrain, Passing Not Allowed, High Platooning

Average speed in direction 1 (km/h) = 92.643673 - 0.000123 (two way volume in veh/h) - 0.010286 (direction 1 volume in veh/h)- 0.011768 (% trucks) - 0.107932 (% RVs) - 0.408499 (Ln effective distance in m)

R^2 = 0.92
N = 34

Average speed in direction 2 (km/h) = 92.910198 - 0.001983 (two way volume in veh/h) - 0.015508 (opposing volume in veh/h)- 0.010152 (% trucks) - 0.072191 (% RVs) - 0.116592 (Ln effective distance in m)

R^2 = 0.74
N = 33

Equation NRPNA (Combined average speed): Rolling Terrain, No Passing Lane, Passing Not Allowed, Low Platooning

Average speed (combined for both directions) in km/h = 118.911562 - 0.006551 (two way volume in veh/h) - 0.002009 (opposing volume in veh/h) - 0.033498 (% trucks) - 0.092668 (% RVs) - 2.948003 (Ln effective distance in m)

R^2 = 0.95
N = 34

Equation NRPNAH: Rolling Terrain, No Passing Lane , Passing Not Allowed, High Platooning

Average speed in direction 1 (km/h) = 89.553633 - 0.000344 (two way volume in veh/h) - 0.010929 (direction 1 volume in veh/h)- 0.028004 (% trucks) - 0.116529 (% RVs) - 0.085323 (Ln effective distance in m)

R^2 = 0.91
N = 34

Average speed in direction 2 (km/h) = 101.623858 - 0.00205 (two way volume in veh/h) - 0.015454 (opposing volume in veh/h)- 0.019698 (% trucks) - 0.064511 (% RVs) - 1.058305 (Ln effective distance in m)

R^2 = 0.74
N = 34

Two Lane Highway With Passing Lane

Equation LPA (Combined Average Speed): Level Terrain, Passing Lane, Passing Allowed, Low Platooning

Average speed (combined for both directions) in km/h = 119.8799- 0.008408 (two way volume in veh/h) - 0.002844 (opposing volume in veh/h) - 0.049708 (% trucks) - 0.138742 (% RVs) - 2.768871 (Ln effective distance in m) + 0.691726 (Ln passing lane length in m)

R^2 = 0.97
N = 34

Equation LPAH: Level Terrain, Passing Lane, Passing Allowed, High Platooning

Average speed in direction 1 (km/h) = 91.380446 - 0.003972 (two way volume in veh/h) - 0.00672 (direction 1 volume in veh/h)- 0.040421 (% trucks) - 0.126444 (% RVs) - 0.701888 (Ln effective distance in m) + 1.593516 (Ln passing lane length in m)

R^2 = 0.97
N = 34

Average speed in direction 2 (km/h) = 105.643595 - 0.006344 (two way volume in veh/h) - 0.010498 (opposing volume in veh/h)- 0.06089 (% trucks) - 0.094794 (% RVs) - 0.934566 (Ln effective distance in m) + 0.169761 (Ln passing lane length in m)

R^2 = 0.80
N = 34

Equation RPA (Combined Average Speed): Rolling Terrain, Passing Lane, Passing Allowed, Low Platooning

Average speed (combined for both directions) in km/h = 117.727194 - 0.008809 (two way volume in veh/h) - 0.002969 (opposing volume in veh/h) - 0.06284 (% trucks) - 0.129757 (%RVs) - 2.449255 (Ln effective distance in m) + 0.608665 (Ln passing lane length in m)

R^2 = 0.97
N = 34

Equation RPAH: Rolling Terrain, Passing Lane, Passing Allowed, High Platooning

Average speed in direction 1 (km/h) = 99.135278 - 0.000874 (two way volume in veh/h) - 0.009101 (direction 1 volume in veh/h)- 0.054945 (% trucks) - 0.20672 (% RVs) - 0.670158 (Ln effective distance in m) + 0.475088 (Ln passing lane length in m)

R^2 = 0.92
N = 34

Average speed in direction 2 (km/h) = 116.347622 - 0.007039 (two way volume in veh/h) - 0.008475 (opposing volume in veh/h)- 0.065631 (% trucks) - 0.043711 (% RVs) - 2.257461 (Ln effective distance in m) + 0.235913 (Ln passing lane length in m)

R^2 = 0.81
N = 34

Equation LPNA (Combined Average Speed): Level Terrain, Passing Lane, Passing Not Allowed, Low Platooning

Average speed (combined for both directions) in km/h = 116.494943 - 0.00458 (two way volume in veh/h) - 0.005702 (opposing volume in veh/h) - 0.000757 (% trucks) - 0.152793 (% RVs) - 3.574117 (Ln effective distance in m) + 1.414835 (Ln passing lane length in m)

R^2 = 0.93
N = 34

Equation LPNAH: Level Terrain, Passing Lane, Passing Not Allowed, High Platooning

Average speed in direction 1 (km/h) = 95.118455 - 0.000449 (two way volume in veh/h) - 0.009647 (direction 1 volume in veh/h)- 0.020951 (% trucks) - 0.16526 (% RVs) - 2.298813 (Ln effective distance in m) + 2.645811 (Ln passing lane length in m)

R^2 = 0.98
N = 34

Average speed in direction 2 (km/h) = 101.52954 - 0.001503 (two way volume in veh/h) - 0.021797 (opposing volume in veh/h)- 0.074933 (% trucks) - 0.088733 (% RVs) - 1.099821 (Ln effective distance in m) + 0.642561 (Ln passing lane length in m)

R^2 = 0.53
N = 34

Equation RPNA (Combined Average Speed): Rolling Terrain, Passing Lane, Passing Not Allowed, Low Platooning

Average speed (combined for both directions) in km/h = 113.56388 - 0.005093 (two way volume in veh/h) - 0.005327 (opposing volume in veh/h) - 0.017878 (% trucks) - 0.139743 (% RVs) - 3.23117 (Ln effective distance in m) + 1.371923 (Ln passing lane length in m)

R^2 = 0.95
N = 34

Equation RPNAH: Rolling Terrain, Passing Lane, Passing Not Allowed, High Platooning

Average speed in direction 1 (km/h) = 88.585044 - 0.000467 (two way volume in veh/h) - 0.009679 (direction 1 volume in veh/h)- 0.046633 (% trucks) - 0.159063 (% RVs) - 1.520258 (Ln effective distance in m) + 2.546628 (Ln passing lane length in m)

R^2 = 0.97
N = 34

Average speed in direction 2 (km/h) = 94.307229 - 0.002531 (two way volume in veh/h) - 0.016306 (opposing volume in veh/h)- 0.020967 (% trucks) - 0.033967 (% RVs) - 0.386696 (Ln effective distance in m) + 0.18119 (Ln passing lane length in m)

R^2 = 0.67
N = 34

4.7 Level of Service Estimation

For given sites, the regression equations enable an estimation of platooning and average speed. These can be used in conjunction with the criteria contained in the HCM (1985) to assess the level of service. The following criteria apply to two lane highways with design speed of 100 km/h or higher (based on HCM 1985).

Level of Service Criteria

LOS	Level Terrain		Rolling Terrain	
	% Time Delay	Avg. Speed Km/h	% Time Delay	Avg. Speed Km/h
A	≤ 30	≥ 93.4	≤ 30	≥ 91.8
B	≤ 45	≥ 88.6	≤ 45	≥ 86.9
C	≤ 60	≥ 83.7	≤ 60	≥ 82.1
D	≤ 75	≥ 80.5	≤ 75	≥ 78.9
E	> 75	≥ 72.5	> 75	≥ 64.4
F	100	< 72.5	100	< 64.4

Note: For design speed less than 100 km/h, reduce the average speed by about 6.5km/h.

4.8 Length of Lane and Effective Distance

For an illustration of the effect of a passing lane, selected outputs of the TWOPAS model and those of regression equations are used here. Figure 4.1 shows percent of vehicles in platoons for cases of with and without a passing lane of 1.6 km length. The road section is on level terrain with no overtaking restrictions. The assumption of low platooning at the entrance was used here. Traffic volume is 1500 vehicles/hour, with fifty percent of traffic being in the advancing direction. The traffic volume consists of 10% trucks and 10% RVs. Results show clearly that the effect of passing lane becomes negligible after about 8000m from the beginning of the passing lane.

The influence of passing lanes of different lengths are illustrated in Figure 4.2. Although the longer the lane, the higher is its effect in terms of reducing platooning, the cost-effectiveness and net benefits for lanes longer than 2 kms are not higher than for shorter lanes. As illustrated in Chapter 8, a 2 km lane appears to be an cost-effective length. As for the effective distance, for a volume level of 1500 veh/h, 8 km appears to be appropriate.

An examination of spot speed information contained in Figure 4.3, for the case of overtaking allowed, suggests that even under no restrictions on overtaking, the effect of passing lane becomes very small after about 13 kms. In the case of passing not allowed, as illustrated, the effective distance of passing lanes is further reduced (Figure 4.4). The spot speed information displayed in Figures 4.3 & 4.4 was obtained from the use of TWOPAS model.

4.9 Use of Macroscopic Models: Sensitivity Analyses

Selected sensitivity analyses were carried out in order to illustrate changes in percent of vehicles in platoons and the average speed caused by variations in:

- traffic volume,
- composition of traffic,
- restrictions on passing (i.e., the extent of no passing zones), and
- terrain

In all cases, a passing lane of 2 kms is used for a road section of 8 kms. Results are presented in Figures A.1 to A.24 of Appendix A.

An examination of these illustrations suggests the following observations.

FIG.4.1: % IN PLATOONS (ADV. DIRECTION)

V=1500VPH 50/50 SPLIT T=RVs=10% PASSING

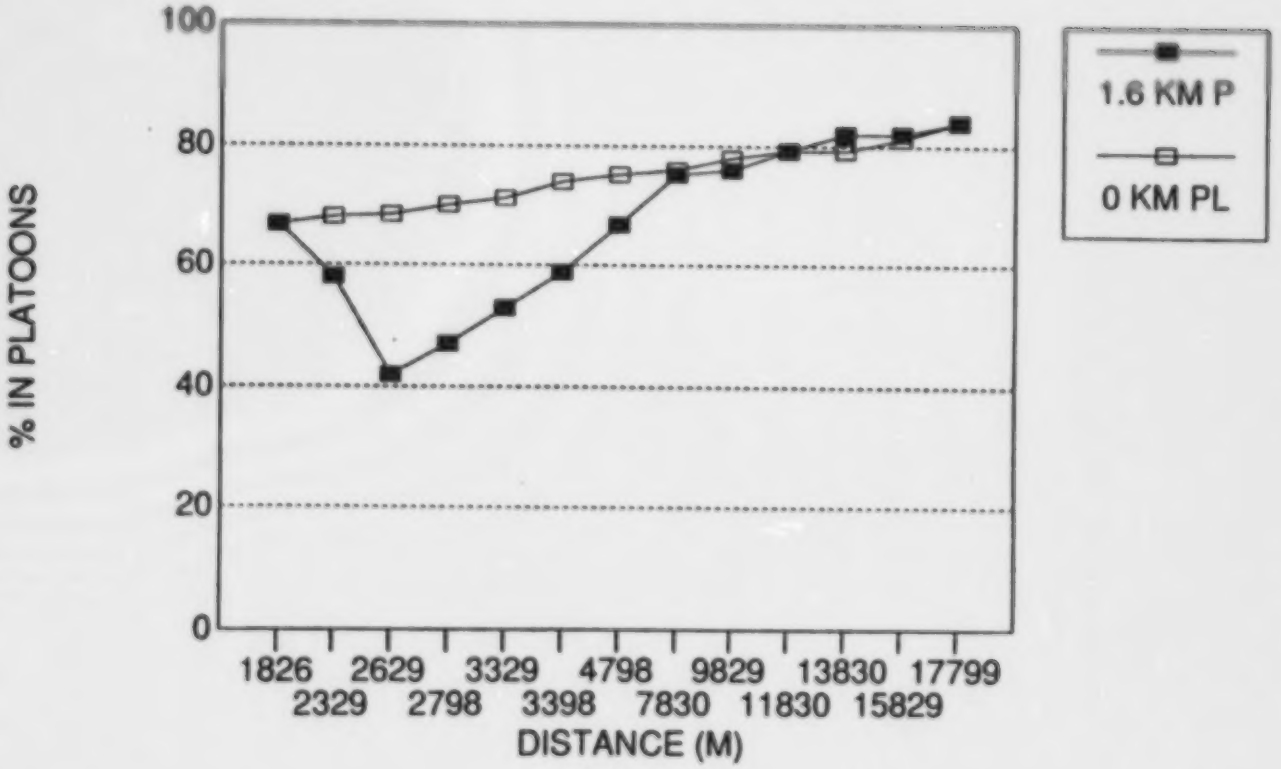


FIG.4.2: % IN PLATOONS (ADV. DIRECTION)

V=1500VHP 50/50 SPLIT T=RVs=10% PASSING

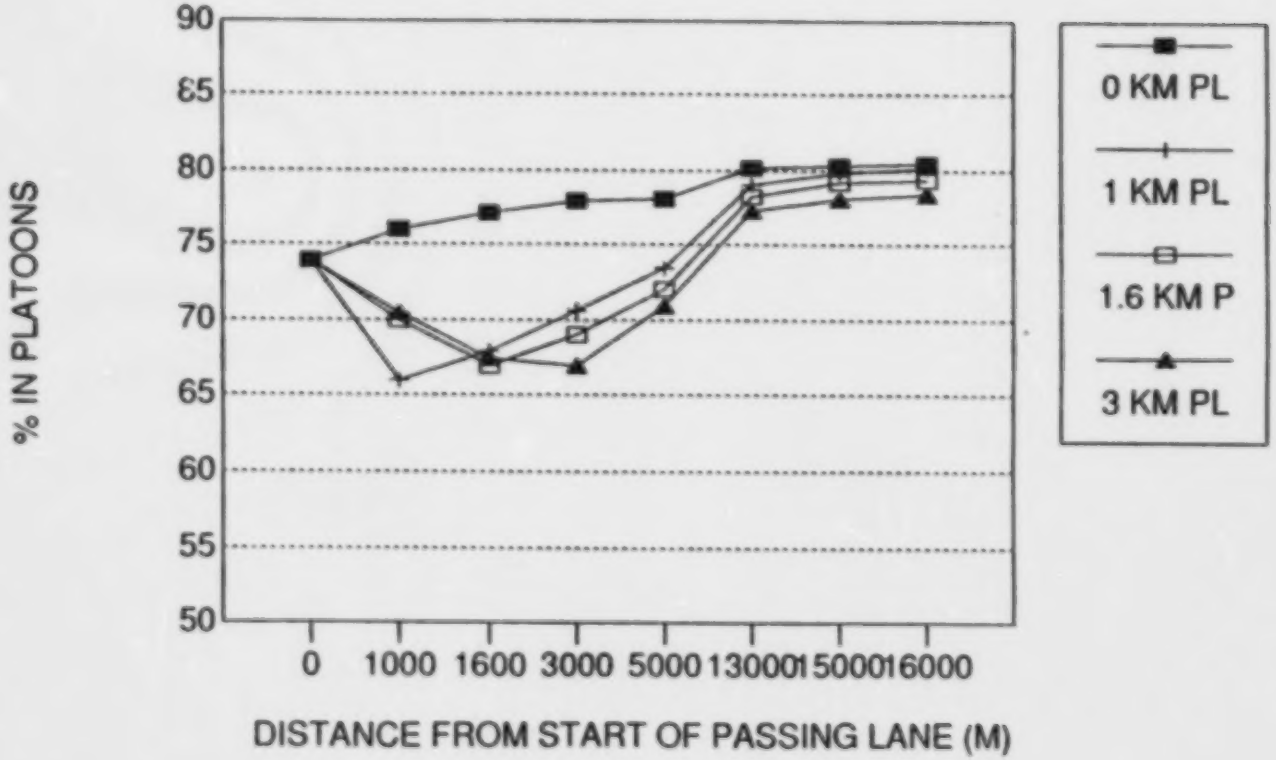


FIG.4.3: SPOT SPEED

V=1500VHP 50/50 SPLIT T=RVs=10% PASSING

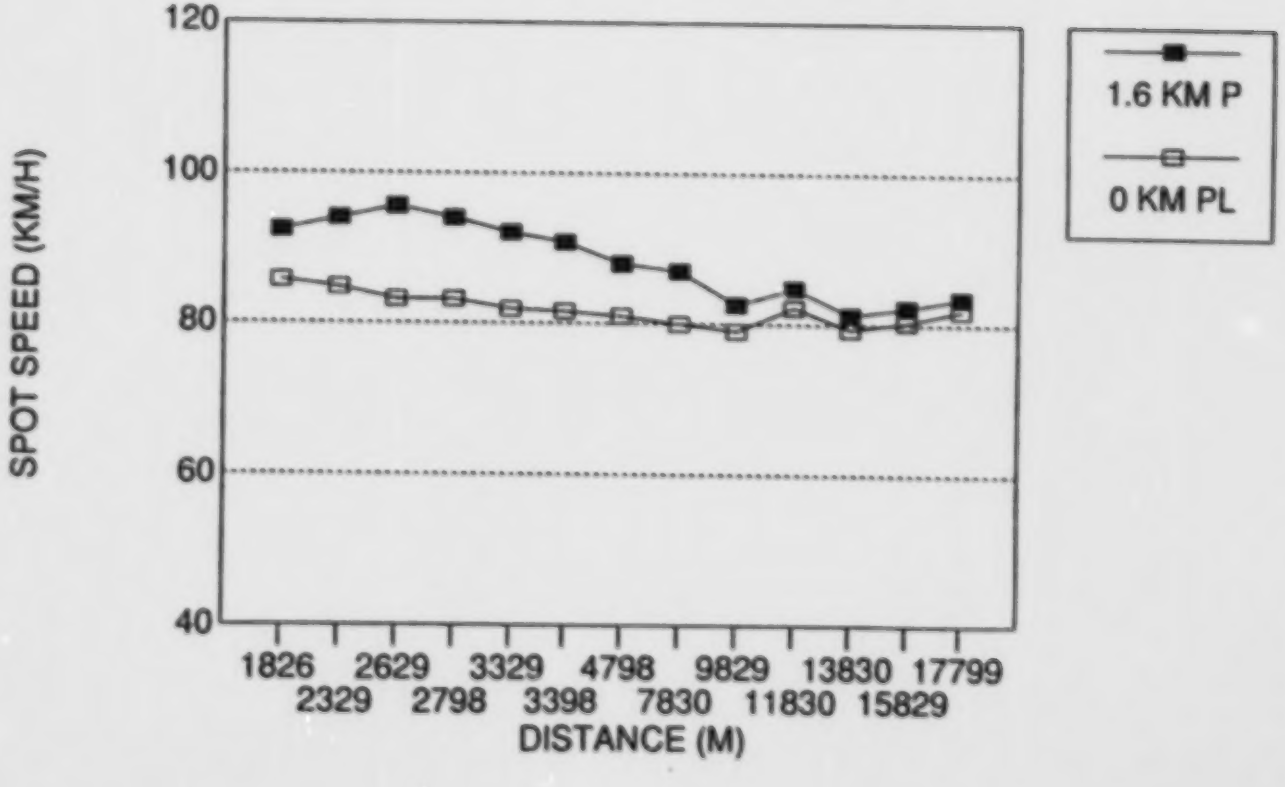
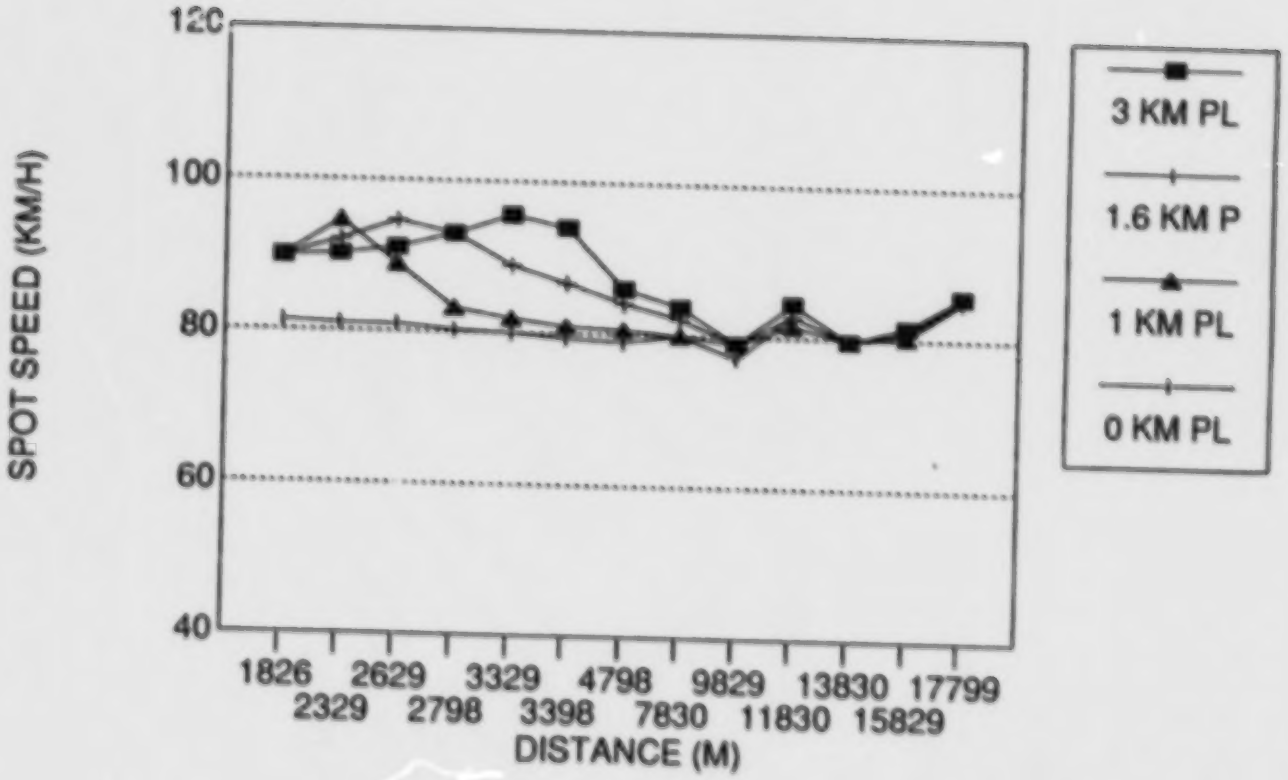


FIG.4.4: SPOT SPEED



- Traffic volume has a major effect on platooning and average speed.

- Restrictions on overtaking has an appreciable effect on platooning and average speed.

- For otherwise identical conditions, including overtaking restrictions, there is little difference between the operational performance of highway sections in level and rolling terrain in terms of platooning and average speed. That is, the presence of alternating minor grades do not appear to cause any adverse effects on vehicle performance.

- For level and rolling terrain, the presence of trucks and RVs has much less effect on platooning and average speed than expected. In relative terms, trucks and RVs have about the same effect on the operational performance of a two lane highway. Comments on minor differences have already been noted elsewhere in this report.

Chapter 5

SAFETY EFFECTIVENESS OF PASSING LANES

5.1 Causes of Two Lane Highway Accidents

Accidents on two lane highways have been statistically related to traffic volume level, composition of traffic, geometric design features including highway cross section elements, roadside hazards, and environmental factors. In the context of auxiliary lanes, platooning and delays induced by slow moving vehicles as contributory factors to accidents are of special interest.

Under conditions of increasing platooning and dropping speed, safety hazard increases due to unsafe passing manoeuvers. Increasing traffic volume on level, rolling or hilly terrain results in a higher percentage of vehicles in platoons. According to early statistics, accident involvement rate rises with the dropping operating speed of the highway. Recent statistics indirectly confirm this phenomenon in the form of establishing a correlation between traffic level and accident rate. Increasing traffic volume on a two lane highway, of course implies higher platooning and lower operating speed.

The recent development of increasing length of commercial vehicles should be mentioned here due to its potential safety hazard. The distance to complete a passing manoeuver, among other factors, is influenced by the length of the vehicle being overtaken as well as that of the vehicle initiating the manoeuver. In the absence of adequate distance for overtaking activity when long vehicles are present in the traffic stream, a safety hazard may be encountered.

The provision of auxiliary lanes should enhance safety by increasing safe passing opportunities. The role of climbing lanes in enhancing safety of two lane highways has been covered in a previous project [2]. Also, a review of safety effectiveness of climbing lanes by other recent studies indicated that this subject is worthy of further investigation due to information gaps [20]. In the following sections, available information on the safety effectiveness of passing lanes is summarized and a method is described for estimating accident reduction due to passing lanes.

5.2 Effectiveness of Passing Lanes in Improving Safety: State of Knowledge

Available accident information for Ontario two lane highways

does not permit inferences to be drawn on the safety effects of auxiliary lanes. As for the type of accidents that could be affected, it should be noted that approaching (head-on) non-intersection accidents on two lane roads account for about 2% of all accidents. However, these constitute 17.5% of all fatal accidents and that for most of the approaching accidents, improper passing is the given as the apparent driver action [29].

In theory, passing lanes can increase the passing opportunities and can enhance safety. In order to verify this hypothesis, recent studies and data were examined. Highlights of findings are noted below.

. A U.S. study sponsored by the Federal Highway Administration (FHWA) reported the following relative accident rates for highway improvements [15].

Table 5.1

Relative Accident Rates (i.e., Index) for Improvement Alternatives

	All Accidents	Fatal & Injury Accidents
Conventional two-lane highway	1.00	1.00
Passing lane section	0.75	0.70
Four lane section	0.65	0.60

. A california study, according to Rinde, analyzed 23 sites in level, rolling, and mountainous terrain and found a reduction in accidents amounting to 11 to 27%, depending upon road geometrics. A highly favourable accident rate reduction of 42% was found for 13 sites in level or rolling terrain [21].

. Another estimate of the safety effectiveness of passing lanes was reported by Harwood & St. John [16]. Data from 22 sites examined by Harwood and St. John showed an accident rate reduction attributable to passing lanes amounted to 9% for all accidents and 17% for fatal and injury accidents (Table 5.2). On the basis of combined data from a number of studies, Harwood suggested that passing lane installations reduce accident rates by 25% [13,16].

Table 5.2

Accident Reduction Effectiveness of Passing Lanes

	Percent Reduction	
	All Accidents	Fatal & Injury Accidents
Two lane road with passing lane; level and rolling terrain (adequate geometrics)+	9%	17%
Passing lane safety effectiveness, based on combined data from a number of studies++	25%	

+ Reference 15.
++ References 15,21.

- Harwood et. al. assessed the safety effectiveness of passing lanes on the basis of 1 to 5 years of accident data at 13 passing lane sites and 13 matched 2-lane sections [22]. The passing lanes were found to have 38% fewer total accidents and 29% fewer severe accidents (per million vehicle miles).

- A recent study of safety of passing lanes in Michigan, reported by Jain & Taylor, resulted in data shown in Tables 5.3 & 5.4 [11]. The percentage reduction, based on accidents/100 million vehicle-km, ranges from 12.6% for ADT less than 500 to 28.4% for ADT of 10,000 to 15,000. For some reason that is not explained by Jain & Taylor, the reduction for ADT range of 5,001 to 10,000 was only 8.7%. The fatal accident rate reduction was much more pronounced (e.g., 81.0% for ADT range of 5,000 - 10,000). It should be noted that the Jain & Taylor study combined climbing lanes and passing lanes in the study of accidents. For the case of road sections with passing lanes/climbing lanes, accidents were studied for "within the passing lane/climbing lane" and no attempt was made to investigate the downstream effects of such lanes on accident reduction.

- The studies reviewed above indicate that passing lanes could reduce accidents within the lane by at least 20%.

Table 5.3

Michigan Experience of Accidents on Two Lane Roads: With and Without Passing Lanes

	Accidents/100 million veh-km		
	ADT		
	1-500	5001-10,000	10,000-15,000
Without passing lane			
Injury	37.63(20.2%)	46.28(27.5%)	101.94(42.1%)
Fatal	1.47(0.8%)	1.59(1.0%)	1.55(0.7%)
PDO	147.01(79.0%)	120.15(71.5%)	138.52(57.2%)
Total	186.11(100.0%)	168.02(100.0%)	242.01(100.0%)
Within passing lanes			
Injury	26.10(16.1%)	37.15(24.2%)	36.56(21.1%)
Fatal	0.37(0.2%)	0.31(0.2%)	1.31(0.8%)
PDO	136.16(83.7%)	115.90(75.6%)	135.34(78.1%)
Total	162.63(100.0%)	153.36(100.0%)	173.21(100.0%)

Source: Reference 11.

Table 5.4

Accident Reduction Due to Passing Lane
(Accidents/100 Million Vehicle-Km)

	Fatal Acc. Rate	Person Killed Rate	Injury Accident Rate	Person Injured Rate	PDO Accident Rate	Total Accident Rate
ADT<5000						
Without PL	1.49	1.80	37.60	60.04	146.99	186.08
Within PL	0.37	0.37	26.10	39.03	136.17	162.64
Reduction	1.12	1.43	11.50	21.01	10.82	23.44
5000<ADT ADT<10000						
Without PL	1.62	1.83	46.30	76.63	120.14	168.06
Within PL	0.31	0.31	37.17	58.48	115.91	153.39
Reduction	1.31	1.52	9.13	18.15	4.23	14.67
ADT>10000						
Without PL	1.55	1.86	63.33	104.85	138.47	203.35
Within PL	1.31	1.31	36.54	58.79	135.36	173.21
Reduction	0.24	0.55	26.79	46.06	3.11	30.14

Source: Reference 11.

. Accident are expected to be reduced beyond the lane due to reduced platooning and increased average speed.

As for safety of passing lane installation in terms of their design, the following observations are extracted from the literature:

. Examination of cross-centreline accidents involving vehicles travelling in opposite directions on the highway did not indicate safety differences between passing lanes where passing was allowed, and sites where passing was not permitted in the opposing direction, provided that sight distance was adequate. Under appropriate conditions, the use of widened roadway section by both directions of traffic did not appear to cause any safety problems at properly designed sites and volume levels of 400 vehicles/hour in one direction of travel. Furthermore, accident rates for the widened (passing lane) area and cross-centreline accidents rates at such sites were lower than those of comparable sections of conventional two lane highway [15,16,21]. However, it has been suggested by Rinde that opposing traffic not be allowed to use the passing lane if traffic volume exceeds 3000 vehicles per day [21].

. Safety investigations did not uncover special problem areas on sites with auxiliary lanes. Field observations of traffic conflict and erratic manoeuvers at the lane drop transition areas of auxiliary lanes suggest that these operate smoothly. In total, a very small percentage (i.e., 1.3%) of the vehicles using the lane drop transition zones caused a traffic conflict. Erratic manoeuver rates of 0.4% and 0.3% were observed for centreline and shoulder encroachment, respectively [15,16].

In summary:

. auxiliary lanes have been effective in reducing accidents to the extent of about 25% or higher as compared to comparable two lane sections without an auxiliary lane.,

. no safety issues relate to the features of auxiliary lanes; lane additions (diverge) and merge areas are not known to pose any marked safety hazards provided that adequate sight distance is provided at lane drop areas in case a vehicle has to stop in case of a problem.

5.3 The Use of Climbing Lanes: Experience of Transportation Agencies

Available information attests to the belief held in professional circles that there is a direct relationship between accidents and speed differences between adjacent sections of a highway and within a traffic stream. The response of

transportation agencies has been programs of increasing the opportunities for vehicles to pass slow moving vehicles. The provision of auxiliary lanes is a well accepted principle.

Transportation agencies commonly provide passing lanes on the basis of level of service and operational warrants (e.g., an assured passing opportunity of 25%). Field studies show that auxiliary lanes are generally used by slow moving vehicles, thus providing an opportunity for the faster traffic to continue in the through lane. In situations where slower moving vehicles continue to use the through lane or in the absence of slower moving vehicles to be overtaken, faster traffic uses the passing lane.

Formal safety warrants have not been defined, although safety is a major consideration in the provision of auxiliary lanes [23].

5.4 Methodology for Estimating Accident Involvement Rates

A number of approaches were investigated for the estimation of safety improvement associated with passing lane options under specified conditions. A detailed literature search was initiated for obtaining safety data applicable to two lane highways. Most available information sources, reported above, turned out to be rather limited in scope for application in this study.

The desirable attributes of a method for estimating the safety effects of passing lane options were identified. Ideally, a safety model should enable the estimation of accident reduction due to the provision of a passing lane as a function of:

. changes in platooning
. changes in average speed

The above measures of effectiveness would incorporate the effects of passing lane length, the effective distance of the passing lane, traffic volume and its composition, directional split of traffic, and terrain. Although change in platooning is a better measure for safety impact studies, there are no known data that could be used to develop such a model. On the other hand, in this study, the reduction in accident rate due to passing lane-induced improvement in average speed is estimated through an equation developed for this purpose.

In conjunction with Ontario accident statistics applicable to two lane highways, the information presented above can be used to assess safety improvement obtainable from passing lanes. However, these information items will not enable safety effectiveness assessment of options should there be significant differences in terms of enhancing traffic flow conditions. These

can therefore be regarded as useful information to be used mainly for checking other approaches.

Two accident exposure estimation equations were developed in a previous MTO study on climbing lanes. These equations expressed accident rate as a function of speed reduction due to the effect of traffic and/or upgrades. It is intended to use one of these equations (noted below) in the present project. The answers obtained and checked against current accident statistics and the above noted U.S. safety information.

As compared to a highway section with normal operating conditions, a drop in operating speed is expected to result in higher accidents.

For speed reduction of 0 to 15 km/h:

Accidents per 100 million vehicle km of travel =
132.441 + 22.085 (speed reduction in km/h)

The above equation can be used in a number of ways for the estimation of accident involvement rate. For a two lane section without a passing lane the accident rate could be quantified by using the magnitude of speed reduction in comparison to a section with a passing lane. In order to estimate accident reduction due to a passing lane, the product of the coefficient part of the equation with speed improvement level (in km/h) results in estimated reduction on a 100 million vehicle-km basis.

As compared to a two lane section without a passing lane, the improvement in average speed is used as a basis for accident estimates. For 0 to 15 km/h speed improvement, (as estimated through the use of models developed in this study), the following equation can be used:

Reduction in accidents
per 100 million vehicle-km
of travel due to the
provision of a passing lane = 22.085 (average speed improvement in km/h)

The basis for the above equation originates from slow-vehicle induced accident data collected by Solomon on level as well upgrade sections [30]. It should be pointed out that although St. John and Harwood have recently questioned some aspects of Solomon's data base, they have not offered any alternatives except a recommendation for further research into this subject [20]. The Solomon data base has been widely used over the years (e.g., Glennon [30], AASHTO [31], and Khan et.al. [2].

For the development of the microcomputer program, the above relationship between safety and average speed increase due to passing lane was used. The equation is applicable for speed improvements from 0 to 15 km/hour. This range of speed change is adequate to cover most if not all cases of installing passing lanes on two lane highways. It should be highlighted here that a better insight into the subject of safety and improved accident data base could be gainfully used in the future to update the methodology reported above.

It is appropriate to check the validity of the above equation against known safety data or estimates reported in the literature.

- For a two lane highway on level or rolling terrain, operating at average speed close to desired speed by road users, the speed reduction could be considered to be zero. The estimated accident rate is therefore equal to 132.441 accidents per 100 million vehicle km of travel. This compares very well with the Ontario average of 131 accidents/100 million vehicle-km for two lane roads [32,33].

- For a two lane highway (level terrain) without a passing lane, on the basis of an 8 km section, the use of equations reported in Chapter 4 in conjunction with accident rate estimation model described above results in accidents shown in Table 5.5. These accidents are compared with the Michigan safety data. These two sets of accidents compare very well for the entire range of traffic volume. (For further details of the two lane highway section, see example Chapter 8).

- For the above noted two lane highway section of 8 kms (level terrain) with a 2 km long passing lane, the estimated accident reduction as obtained from models developed in this study are shown in Table 5.5. Also shown are the accident reductions from the Michigan data base. For AADT<5000 and for AADT>10,000, the Michigan data match well with estimates obtained in this study. However, for reasons that have not been reported by Jain and Taylor, the accident reduction experience for the middle of the range volumes of 5000<AADT<10,000 are rather low and are not logical [11].

- The reduction in accidents due to passing lane installation as a percentage of two lane highway accidents varies from 14.3% (for AADT of 1724) to 25.0% (for AADT of 8621). These answers are logical since the safety effectiveness of an auxiliary lane increases with traffic volume. Furthermore, the level of safety effectiveness is consistent with the guidelines reported above (i.e., about 25% accident reduction estimate).

Table 5.5

Comparison of Accident Estimates Obtained From the Equation and Michigan Experience Accident Rate/100m Vehicle-Km

	AADT<5000		5000<AADT<10,000		AADT>10,000
DHV	300	500	1000	1500	
AADT	1724	2874	5747	8621	>10,000
Acc. Rate Without PL					
. Equation	154.53	158.94	165.57	176.61	
. Michigan Data	186.08		168.06		203.35
Reduction Rate/100m veh-km) & % Reduction					
. Equation	22.09 (14.3%)	26.50 (16.7%)	33.13 (20.0%)	44.17 (25.0%)	
. Michigan Data	23.44 (12.6%)		14.67 (8.7%)		30.14 (14.8%)

Source: See Table 5.4 for Michigan data.
For details of estimates attributed to safety equation, see Chapter 8.

To conclude, the safety model reported in this chapter is useful for the study of safety effectiveness of passing lane options since it works on relative differences in average speed between "without" and "with" passing lane cases and the effect of traffic volume is taken into account. Also, the accident model provides results that are logical and consistent with known data.

Chapter 6

VERIFICATION OF PLATOONING AND AVERAGE SPEED MODELS

6.1 Introduction

Models developed for estimating the operational performance of two lane highways both with and without auxiliary lanes have to be tested for their validity against field data. The verification of equations used for the analysis of climbing lanes has been reported in reference 2. A similar process was followed in this study to test the validity of platooning and average speed equations reported in Chapter 4.

6.2 An Overview of the Verification Process

At selected sites platooning and average speed were measured. The traffic and geometric characteristics of test sites were used in the regression equations for the estimation of platooning and average speed. A comparison of survey result with estimates obtained from the use of models developed in this study formed the basis of verifying the equations.

The results of field verification serve two interrelated purposes. Although the TWOPAS model has been tested extensively by other researchers for generally level and rolling terrain, the validity of regression equations based on its outputs offers further confidence in this microsimulator. The ability of the regression equations to predict in a reliable fashion the operational performance of traffic on two lane highway sections is necessary so that these equations would replace the TWOPAS model for most auxiliary lane analyses. In the following sections of this chapter, characteristics of sites and results of comparing field data and model estimates are described.

6.3 Choice of Sites

Since regression equations developed cover two lane highway sections with and without passing lanes, it was appropriate to study each type of site. Sites "with passing lane" and "without passing lanes" were identified for field data collection on the performance of two lane highway sections. Three such sites on Highway 17 were identified. One site was without a passing lane and two had passing lanes.

6.4 Field Study Methods

Spot speed, platooning and other characteristics of traffic were measured at the entrance and at the end of selected sites.

Each site was surveyed for one hour. Radar meters enabled the recording of vehicle speed and video cameras were used to observe platooning, traffic volume, composition and directional split. The videotape was also used for estimating vehicle speed.

From radar meter readings, spot speeds at the entrance and end of observed sections were estimated. Average of these spot speed was used as an estimate of the average speed over the section of the highway under study. The extent of platooning (based on a headway of 4 seconds or less) was measured from the videotape.

6.5 Comparison of Models with Field Data

The regression equations developed in this study (reported in Chapter 4) were used to estimate speed and platooning for the study sites. That is, geometric and traffic characteristics of sites were used as inputs to the equations for the estimation of speed and platooning. In the following sections, study sites are described and results of comparison of model estimates with field observations are presented.

6.5.1 Site Without A Passing Lane

The site without a passing lane is located on Highway 17 near the intersection of Highway 44. A 4,500m long section, with mixed segments of "passing allowed" and "passing not allowed", was used for field observation. The design speed for this section appears to be 100 km/h.

Main features of the site "without a passing lane" are summarized below.

- Terrain: level
- Length of section = 4,500 m
- Traffic volume = 851 vehicles/hour (for both directions)
- Advancing direction traffic = 54%
- Trucks = 7%
- Recreational vehicles = 1%

Percent of Vehicles in Platoons:
(Advancing Direction)

Field observations:

. Entrance	53.0%
. End of road section	60.0%

Estimated Platooning (Use of Models):
(end of road section,
advancing direction)

. Equation NLPAH -- no passing lane, level terrain, passing allowed, high platooning	51.0%
. Equation NLPNAH -- no passing lane, level terrain, passing not allowed, high platooning	66.0%
. Equation NLPA -- no passing lane, level terrain, passing allowed, low platooning	40.0%
. Equation NLPNA -- no passing lane, level terrain, passing not allowed, low platooning	55.0%

Average Speed, Advancing Direction:

Field observation	87.3 km/h

Estimated Average Speed (Use of Models):

. Equation NLPAH -- no passing lane, level terrain, passing allowed, high platooning	87.6 km/h
. Equation NLPNAH -- no passing lane, level terrain, passing not allowed, high platooning	84.2 km/h
. Equation NLPA -- no passing lane, level terrain, passing allowed, low platooning	91.2 km/h
. Equation NLPNA -- no passing lane, level terrain, passing not allowed, low platooning	87.7 km/h

The 60% level of platooning at the end of the road section falls between the estimated platooning levels obtained from equations representing the extreme conditions of overtaking allowed and overtaking not allowed. As noted above, the road section has segments where overtaking is permitted and also there are those sections where overtaking is not allowed. For this site, at the time of field observations, the extent of platooning can be regarded as rather high. Therefore, as expected, the equations simulating the high platooning condition provide a better match with the field data than those based on the assumptions of low platooning.

The average speed estimated from equations match very well with the field result of 87.3 km/h. As expected, the equations based on high platooning condition provide lower estimates of speed than those that represent low platooning. Also, within each category of equations, a lower estimate of speed is obtained when

passing is not allowed as compared to the case when overtaking is permitted.

6.5.2 Site 1 With a Passing Lane

This site with a passing lane is located on Highway 17, north of the Exit "Bruce Street, Renfrew, and Road 20". The road section used for field observations is 6800m and has a mix of zones where passing is allowed and not allowed.

. Terrain: level
. Length of section: 6800m
. Passing lane (northbound direction): 1800m
. Traffic volume: 373 veh/h
. Advancing direction traffic: 56%
. Trucks: 8%
. Recreational vehicles: 1%

Percent of Vehicles in Platoons:
(Advancing Direction)

Field Observations:
. Entrance to the passing lane: 27.0%
. End of road section (6800m away): 25.0%

Estimated Platooning (Use of Models):
(end of road section,
advancing direction)

. Equation LPAH -- with passing lane, level terrain, passing allowed, high platooning 27.0%

. Equation LPNAH -- with passing lane, level terrain, passing not allowed, high platooning 41.0%

. Equation LPA -- with passing lane, level terrain, passing allowed, low platooning 24.0%

. Equation LPNA -- with passing lane, level terrain, passing not allowed, low platooning 38.0%

Average Speed, Advancing Direction:

Field observations 95.2 km/h

Estimated Average Speed (Use of Models):

. Equation LPAH -- with passing lane, level terrain, passing allowed, high platooning 93.8 km/h

. Equation LPNAH -- with passing lane, level terrain, passing not allowed, high platooning 92.2 km/h

. Equation LPA -- with passing lane, level terrain, passing allowed, low platooning 96.3 km/h

. Equation LPNA -- with passing lane, level terrain, passing not allowed, low platooning 94.1 km/h

The field observation of platooning appears to be closer to the estimated result obtained from the equations based on passing allowed conditions. As for average speed, the field estimate of average speed is very close to estimates obtained from the equations. In the case of platooning as well as average speed, the relative estimates obtained from equations are logical, depending upon conditions represented by these equations.

6.5.3 Site 2 With a Passing/Climbing Lane

This 4000m long road section with a passing lane/climbing lane of 1000m is situated on Highway 17 -- south/east of Breezy Heights Road and south of Antrim truck stop. On its northbound direction, it has a grade of 3% and has a passing/climbing lane for northbound traffic. This road section has a mixture of zones where passing is allowed and passing not allowed. The following are the highlights of this study site.

. Terrain: rolling
. Length of section: 4000m
. Length of passing lane: 1000m
. Traffic volume: 960 veh/h (both directions)
. Advancing direction traffic: 61%
. Trucks: 6%
. Recreational vehicles: 1%

Percent of Vehicles in Platoons:
(Advancing Direction)

Field observations:

. Entrance to passing/climbing lane 68.0%
. End of road section 52.0%

Estimated Platooning:
(End of Road Section)
Use of Equations for Rolling Terrain

. Equation RPAH -- with passing lane, rolling terrain, passing allowed, high platooning 45.0%

- Equation RPNAH -- with passing lane, rolling terrain, passing not allowed, high platooning — 51.0%

- Equation RPA -- with passing lane, rolling terrain, passing allowed, low platooning — 41.0%

- Equation RPNA -- with passing lane, rolling terrain, passing not allowed, low platooning — 44.0%

Average Speed, Advancing Direction:

Field observation — 87.2 km/h

Estimated Average Speed
(Use of equations for rolling terrain)

- Equation RPAH -- with passing lane, rolling terrain, passing allowed, high platooning — 90.1 km/h

- Equation RPNAH -- with passing lane, rolling terrain, passing not allowed, high platooning — 87.0 km/h

- Equation RPA -- with passing lane, rolling terrain, passing allowed, low platooning — 90.7 km/h

- Equation RPNA -- with passing lane, rolling terrain, passing not allowed, low platooning — 90.2 km/h

A range of estimated percent of vehicles in platoons obtained from the use of equations compares well with the field result applicable to the end of the section. In this case, the models based on high platooning conditions appear to provide a better correspondence to field results than the low platooning cases. As for average speed, once again, the equation-based estimates are very close to the field results.

Chapter 7

LENGTH, LOCATION AND COST-EFFECTIVENESS OF PASSING LANES

7.1 Length and Location of Passing Lane: MTO's Existing Methodology

In 1975, the Ministry of Transportation, Ontario established criteria for passing lanes, based on the consideration of a percent of highway length with "assured" passing opportunities. According to the guidelines, passing lanes are to be provided where the combination of restricted sight distance and high opposing traffic volume do not result in adequate level of passing opportunities.

The procedure to be followed calls for the calculation of the desired % of assured passing opportunity and its comparison with assured passing opportunity offered for various traffic levels.

1. Estimation of desired assured passing opportunity (APO):

$$\text{Desired APO (\%)} = \frac{\text{Passing lane length in km.}}{[(\ 480Q/V_{adv}) + \text{Passing lane length in km}]}$$

where Q is size of queue (vehicle)
V_{adv} is volume in direction 1
A passing lane length of 1.6 - 2.0 km may be assumed for these calculations.

2. Estimation of Assured Passing Opportunity (APO) without a passing lane:

Assured passing opportunity (%APO) = [(PODS)x(HF)] x 100

where POSD is % of the length of road in which passing sight distance requirements are met

HF = headway factor -- the % of time when headway is equal to or exceeds 25s in the opposing direction -- assuming a design speed of 80-100 km/h; a time of 25s is required to perform a passing operation (use in fractional terms).

The HF values and example calculations are provided in Chapter 8.

3. Comparison of "desired APO" with "APO without a passing lane": If the desired APO is not met, consider this site for a passing lane.

The next step is the estimation of passing lane length and effective distance. The MTO procedure can be used as follows:

$$LF = \frac{480\ Q}{V_{adv}} + \text{length of passing lane in km.}$$

Although the above procedures have a weak theoretical basis, these can be used to obtain some estimates for reference purposes. Example application of the above procedure can be found in Chapter 8.

7.2 Suggested Values for Length of Passing Lane and Effective Distance

On the basis of the macrosimulation models (regression equations) developed in this study, the following values of passing lane length and effective distance are suggested for passing lane analyses.

Anticipated DHV 15 year horizon	Length of Lane (including tapers)	Effective Distance (also called Lane Frequency LF)
500 - 750 veh/h	1,000m-1,600m	13,000m
800 - 1000 veh/h	2,000m	10,000m
Over 1000 veh/h	2,000m	8,000m

By way of comparison, the MTO's existing method with an assumed passing lane length of 2.0 km and Q = 6 suggests a lane frequency of 7.8 km for a DHV of 1000. For Q=4, the LF becomes 5.8 km. According to the above guidelines developed in this study, for DHV of 800 to 1000, a 2 km lane and 10 km lane frequency would be appropriate as a starting point for the cost-effectiveness analysis.

7.3 Effectiveness Concept

For effective use of resources, it is logical that the cost of providing a passing lane should be viewed against the effectiveness of such a lane in improving the safety and

operational efficiency of the two lane highway section under study [31,34]. The measures of effectiveness defined and quantified are the same as those used for the climbing lane case [2]. As a first step, these are quantified in their different original units (e.g., minutes, accidents).

A comparison of single measures of effectiveness against cost of passing lane options can be carried out with much ease. However, estimation of multiple measures of effectiveness requires a relative value approach to obtain a combined measure of effectiveness. The development of such measures leads to the cost-effectiveness assessment of a climbing lane option.

The economic feasibility of a passing lane option is an important activity. It involves the estimation of costs and the valuation of benefits. The criterion of present value of net benefits may be applied, based on the estimation of discounted cash flow over the analysis period.

The methodology for conducting the cost-effectiveness studies as well as the economic feasibility of passing lane options is in effect the same as used for the climbing lane case [2].

7.4 Effectiveness Measures

The effectiveness measures are:

. reduction of delay (hours/year)
. reduction of accident involvement rate/100 million vehicle-km.

The regression equations for the estimation of travel time savings (delay reduction) attributed to a passing lane have been reported in Chapter 4. The number of hours of delay reduction per year could be calculated for various options under study. Also, for one passing lane site, such estimates could be obtained for a number of traffic levels (e.g., design hourly volumes of 300 to 1500).

The methodology for estimating the reduction of accidents was discussed in Chapter 5. The use of a safety model enables the quantification of the reduction of accident involvement rate per 100 million vehicle-km. As in the case of delay, accident reductions could be estimated for various alternatives. Also, such estimates could be defined for a given site with traffic volumes that could be varied from low to a high number of vehicles/hour.

7.5 Multiple Measures of Effectiveness

Following the quantification of multiple measures of

effectiveness, relative values have to be developed. The delay reduction DR and accident reduction AR are to be transformed into relative values. The procedure is described here and an example application can be found in Chapter 8.

For all alternatives under consideration, or for various traffic levels applicable to one alternative, identify the highest value of effectiveness measure. Set it equal to 1 (the highest value on the 0 to 1 scale). Find the remaining values by taking ratios -- e.g., set 7,867 hrs of delay reduction/year = 1. Then the relative value for 3,788 hours/year is = (1/7,867) x 3,788 = 0.48.

Weighting of effectiveness measures is to be carried out next. User-specified weights (W) can be assigned such that:

$W_{DR} + W_{AR} = 1.0$

Weighted effectiveness can now be found.
Weighted effectiveness of an alternative = $(W_{DR})(DR) + (W_{AR})(AR)$.

7.6 Economic Feasibility of Passing Lanes: Estimation of Benefits

For each alternative, or for different traffic levels for one alternative, the dollar value of benefits has to be estimated. A base year is to be defined by the analyst for the calculation of present value of benefits and costs. Benefit measures to be used are:

. delay reduction, and
. reduction in accident involvement rate.

For reconciling the profile of benefits and costs over time, a real rate of return i is to be specified. For benefit-cost analysis "without discounting" of benefits, i=0. Also, the inflation rate f is to be specified by the analyst.

Life of facility N, and therefore the period for analysis is to be defined. A 30 year period is suggested as the default value.

Other factors that have to be specified are:

. VT -- value of saving one vehicle-hour (VT) expressed as $/h in the constant dollar of the base year,

. VAC -- value of reducing one accident involvement, in constant dollar of base year.

7.6.1 Estimation of Benefits "Without Discounting"

Benefits of a passing lane would occur over time. Since the values of VT and VAC are originally specified in the constant dollars of the base year, these could be expressed in the actual dollars of future years by using the inflation factor. As there is no intent to discount the future benefits (i.e., the real rate of return is specified to be equal to zero), the present value of benefits can be found by deflating the benefits at the rate of inflation f. The effects of inflating benefits and then deflating these cancel each other, resulting in constant dollars of the base year.

Benefits/year (in constant $ of base year) =

$$\sum_{n=1}^{N} \left(\frac{\text{(Delay reduction hr/yr) x VT}(1+f)^n}{(1+f)^n} \right) x(1/N) +$$

$$\sum_{n=1}^{N} \left(\frac{\text{Reduction in accident involvement/yr) x VAC}(1+f)^n}{(1+f)^n} \right) x(1/N)$$

= {(Delay reduction in hrs/yr)xVT} +
{(Reduction in accident involvement/yr) x VAC}

7.6.2 Estimation of Benefits "With Discounting"

The use of a real rate of return of i in the calculation of the present values of benefits implies that the present value of future benefits would be less than was the case when benefits were not discounted. The higher the magnitude of discount rate i (the real rate of return), the lower would be present value of future benefits.

The appropriate magnitude of the real rate of return for public projects is a management decision. The use of private sector interest rates over the rate of inflation is an option. However, the nature of benefits of highway investments (i.e., safety, delay reduction) suggests that commercial rates of return may not be appropriate. A value between i = 0 and i = prevailing market real rate of return might be appropriate.

Benefits/year (in constant $ of base year) =

$$\sum_{n=1}^{N} \left(\frac{\text{(Delay reduction (hrs/yr)) x VT}(1+f)^n}{(1+f)^n(1+i)^n} \right) \times (1/n) +$$

$$\sum_{n=1}^{N} \left(\frac{\text{(Reduction in accident involvement/year)xVAC}(1+f)^n}{(1+f)^n(1+i)^n} \right) \times (1/N)$$

$$= \text{(Delay reduction (hrs/yr)xVT)}\left[\frac{(1+i)^N - 1}{i(1+i)^N}\right] \times (1/N) +$$

$$\text{(Reduction in accident involvements/yr)xVACx}\left[\frac{(1+i)^N-1}{i(1+i)^N}\right]x(1/N)$$

7.7 Cost of Passing Lane

For each alternative to be analyzed, the following cost estimates are relevant for inclusion in cost-effectiveness and economic feasibility studies.

1. Construction cost of passing lane/km in the constant dollar of base year,
2. Maintenance cost of passing lane/km in the constant dollar of base year,

From the above two items, cost of a passing lane alternative (in the constant $ of base year) can be estimated:

Cost/year = [(Length of passing lane in km) x Cost/km] x (1/N)

It should be noted that in order to account for uncertainties in traffic projections and in cost estimates, and to render the economic feasibility analysis on the conservative side, the above equation does not discount future maintenance costs. However, for precisely the same reason, the estimated benefits may be discounted.

7.8 Economic Feasibility

All the necessary information has now become available for the estimation of the economic feasibility of alternatives and for conducting sensitivity analyses. The procedure calls for the calculation of net benefits/year (in constant $ of base year).

Net benefits/year in the constant $ of base year
= [(Benefits/year in constant $) - (Cost/year in constant $)]

Sensitivity analyses could be carried out to observe the value of net benefits/year by making changes to i, cost, VT, VAC, and N.

7.9 Cost-Effectiveness of Alternatives

For each alternative or for various traffic levels for a given alternative, cost-effectiveness values could be studied in support of decision-making. Single measures of cost-effectiveness of the following types could be assessed:

- Vehicle-hours of delay reduction/$ of cost
- $ cost/veh-hr of delay reduction
- Accident involvement reduction/million dollar of cost
- $ cost/accident involvement reduction

As for the cost vs. overall effectiveness, plots of the index of overall effectiveness against cost could be examined in order to assess the relative desirability of passing lane alternatives or the effectiveness of a given alternative against its cost.

Chapter 8

MICROCOMPUTER PROGRAM AND EXAMPLE APPLICATIONS

8.1 Program Contents and Logic

The methodological framework and the microcomputer program for its implementation reflect the following requirements established in this study:

- to develop a cost-effectiveness methodology for the evaluation of passing lanes, and
- to develop a practical, user friendly micro-computer-based tool for the evaluation of passing lane options, and to enable a comparative evaluation of passing as well as climbing lane options.

The methodological framework and its constituent parts reported in previous chapters of this report were used as a basis for the development of a microcomputer program, namely Cost Effectiveness of Passing Lanes/Climbing lanes (PCL). A User's Manual and a Programmer's Manual describe the program. This chapter describes the program logic and shows example applications.

The concept of integrating the passing and climbing lane methodologies is shown in Figure 2.1. Figure 8.1 shows the microcomputer program logic.

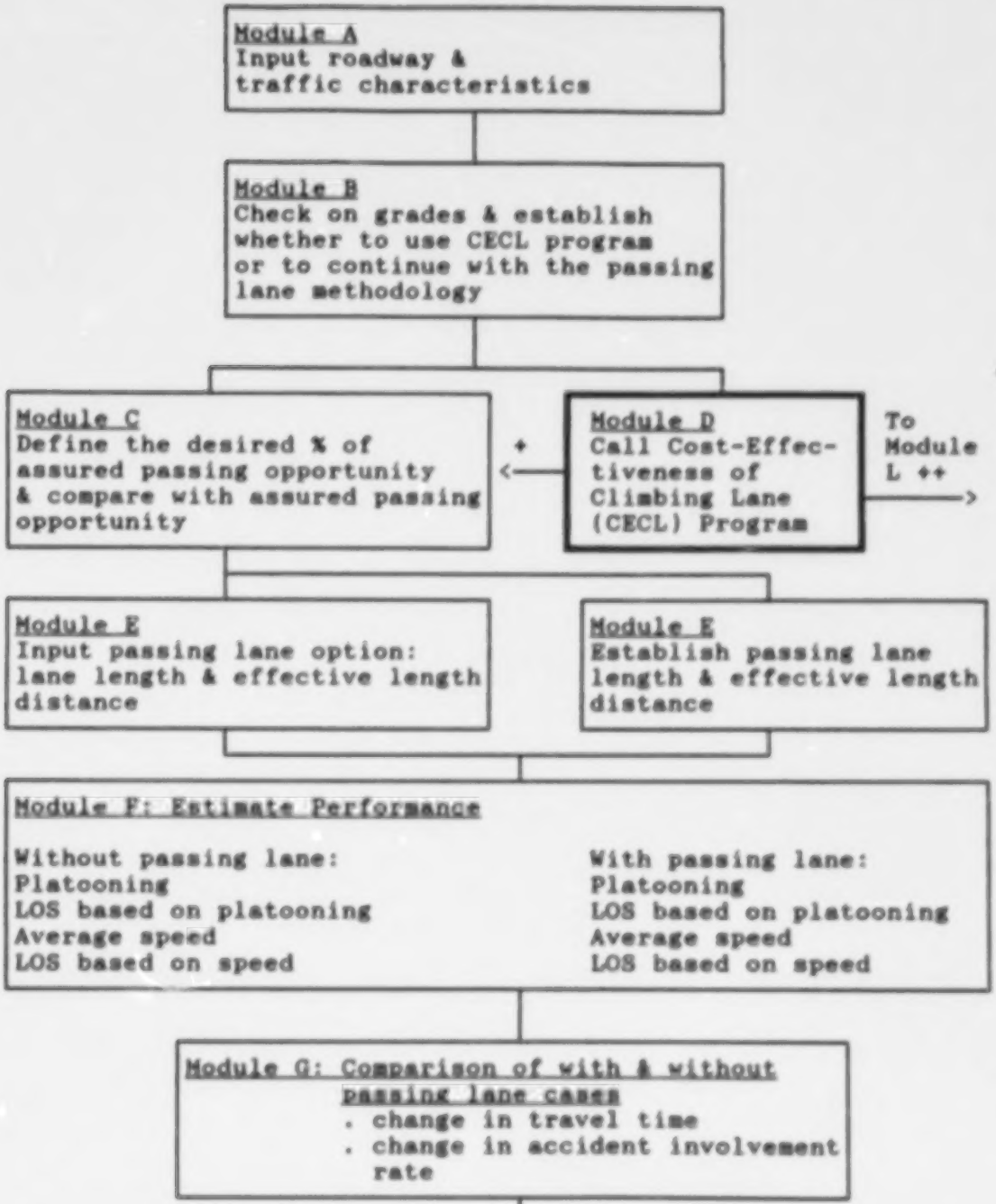
The algorithm described here combines:

- new methodology specifically developed for this study,
- the cost-effectiveness of climbing lane program, CECL, developed in a previous MTO study [2,3,4], and
- the MTO passing lane criterion, based on safe assured passing opportunity.

The methodological structure is designed to be flexible so that if the user prefers, a number of operations could be carried out manually and the required information could be provided as an input to the next module. Also, the user will be able to specify values for a large number of variables, although default values are suggested.

8.1.1 Module A: Roadway & Traffic Characteristics

Module A specifies inputs in terms of roadway and traffic


Module A
Input roadway & traffic characteristics
Module B
Check on grades & establish whether to use CECL program or to continue with the passing lane methodology
Module C
Define the desired % of assured passing opportunity & compare with assured passing opportunity
+
Module D
Call Cost-Effectiveness of Climbing Lane (CECL) Program
To Module L ++
Module E
Input passing lane option: lane length & effective length distance
Module E
Establish passing lane length & effective length distance
Module F: Estimate Performance
Without passing lane:
Platooning
LOS based on platooning
Average speed
LOS based on speed
With passing lane:
Platooning
LOS based on platooning
Average speed
LOS based on speed
Module G: Comparison of with & without passing lane cases
. change in travel time
. change in accident involvement rate
To Module H

\+ if climbing lane warrants are not met

++ if climbing lane warrants met

Figure 8.1: Program Logic

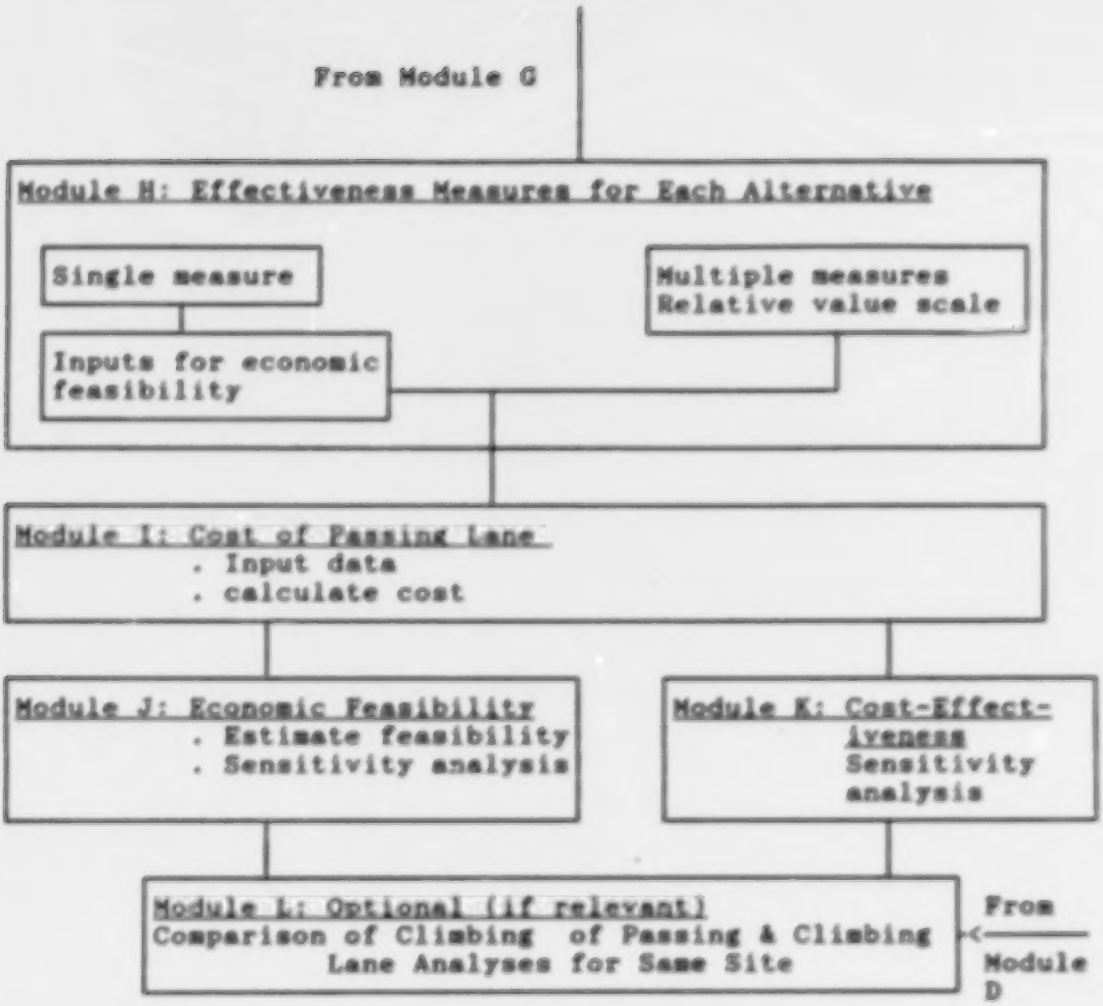

From Module G
Module H: Effectiveness Measures for Each Alternative
Single measure
Multiple measures
Relative value scale
Inputs for economic feasibility
Module I: Cost of Passing Lane
. Input data
. calculate cost
Module J: Economic Feasibility
. Estimate feasibility
. Sensitivity analysis
Module K: Cost-Effectiveness
Sensitivity analysis
Module L: Optional (if relevant)
Comparison of Climbing of Passing & Climbing Lane Analyses for Same Site
From Module D

Figure 8.1: Program Logic (Concluded)

characteristics. The following are the information items and their format.

. Design speed: 100 km/h, 90 km/h

. Type of terrain:
  - level terrain (grades less than 1.5%
  - rolling (grades more than 1.5% but up to 2.5%
  - hilly terrain containing grades more than 2.5% to 3%

. Length of grade (for grades more than 2.5%)

. Passing (overtaking) allowed/not allowed

. Traffic volume (both directions)
  - Design hour volume (DHV)
  - Average Annual Daily Traffic (AADT)

. Directional split
  - Advancing direction = Direction 1
  - Opposing direction = Direction 2

. % Trucks

. % Recreational vehicles (RVs)

. Peak Hour Factor (PHF)

The program is designed to allow user to specify a number of traffic levels for a given site for sensitivity testing purposes -- e.g., DHV = 300, DHV = 500, etc., and corresponding AADTs.

The program accepts inputs for one passing lane/climbing lane location (i.e., candidate site) for one cycle of program use. Multiple sites should be handled separately and results could be compared.

If a road section does not contain any +ve grade more than 2.5%, then such a section may not be analyzed for a climbing lane provision. In such cases, the following designations could be used for describing terrain and there will be no need to specify exact grades and lengths of grade.
- level terrain: in general, grades are just under 1.5%
- rolling terrain: in general, grades are equal to or exceed 1.5% but are not over 2.5%.

In the event that a site is to be analyzed for a climbing lane installation, grades and other information items are to be provided as instructed by the program. A climbing lane example is provided in Section 8.4.

Passing (overtaking) information is to be specified in terms of:

. overtaking allowed (i.e., 0% no passing zones)
. overtaking not allowed (i.e., 100% no passing zones).

Intermediate values of "percent no passing zones" may also be specified (e.g., 50% no passing zones).

This passing information is to be specified by the user implies the following characteristic of the site under study: Percent of length of roadway section in which passing sight distance requirements are met (POSD):

- POSD of 0% -- "100% no passing zones"; overtaking not allowed
- POSD of 20% -- "80% "no passing zones"
-
-
- POSD of 100% -- "0% no passing zones" (overtaking allowed)

The DHV is specified as a percent of AADT. For example, DHV = 17.4% of AADT.

Traffic composition has to be provided as an input to the program. Percent trucks and % RVs are to be specified by the user. Heavy truck selection (i.e., 180 kg/kw & 120 kg/kw) is permitted but used for climbing cases only.

Road cross-section (i.e., lane width, shoulder width, lateral obstructions) are assumed to be in accordance with standards. Therefore no correction factors are required. For climbing cases, due to construction difficulties upgrade, the road geometrics may not be consistent with the level and rolling sections. For this reason, the climbing lane module of the program allows the specification of road cross section.

8.1.2 Module B:

The user has to specify the terrain option following a check on grades. If hilly terrain is chosen, the CECL program module is activated for:

- the study of warrants for a climbing lane, and
- cost-effectiveness analysis of climbing lane options.

If positive grade of more than 2.5% encountered, the user may wish analyze the site for a climbing lane provision. If climbing lane warrants are not met, or if the level of service and economic feasibility analysis do not appear to be favourable, the user may wish to check the site as a candidate for a passing lane.

For details of the computerized design of climbing lane or the analysis of user specified climbing lane, the reader should refer to Chapter 8 of reference 2.

8.1.3 Module C:

This module is devoted to the calculation of the desired % of assured passing opportunity and its comparison with assured passing opportunity offered for various traffic levels. Specifically, the steps involved are:

1. Estimate desired passing opportunity
2. Estimate assured passing opportunity (APO) without a passing lane
3. Compare "desired APO" with "APO without a passing lane". If the desired APO is not met, consider this site for a passing lane.

8.1.4 Module D:

This part of the program calls the Cost-Effectiveness of Climbing Lane (CECL) Program for the analysis of a site as a candidate for a climbing lane. Details of CECL Program are reported in references 2,3 and 4.

8.1.5 Module E: Estimation of Passing Lane Length & Effective Distance

The user is expected to specify passing lane length and effective distance. The length of a passing lane could be specified on the basis of suggested values provided in Chapter 5.

The effective distance, which includes the passing lane length, could extend to the next passing/climbing lane or other location with physical conditions that limit the operation of the two lane highway. The user may wish to refer to suggested values based on this study or use the existing MTO procedure as described in Chapter 4.

The program uses default values of 2,000 m for passing lane length and 8,000 m for effective distance.

8.1.6 Module F & G: Estimation of Performance, Safety; Comparison of With & Without Passing Lane

Module F of the program is devoted to the estimation of platooning, average speed, level of service, and accidents. Two sets of equations are used for the estimation of "percent of vehicles in platoons" (at the end of effective distance) and average speed (for the two way flow) over the effective distance. Set one is based on the assumption of low platooning at the

entrance to the section of the road under study. The second set reflects the high platooning assumption. Sensitivity tests of the program and field validation of equations suggest the desirability of using either the average of high and low platooning cases (generally for low volume roads) or to use the high platooning case (for medium to high volume roads). The computer program offers a choice to the user. The "percent of vehicles in platoons" is used as an indicator of "percent of time vehicles are delayed".

Module G is intended to compare performance with and without passing lane in terms of travel time and safety. The methodology used has been described in Chapter 7.

8.1.7 Module H, I & J: Cost-Effectiveness Studies

These modules calculate costs, economic feasibility and cost-effectiveness of alternatives. Theoretical aspects of these methods for evaluation of passing lane alternatives have been covered in earlier chapters. User may wish to specify all inputs used in the calculation of these factors. Default values are provided only for illustration purposes.

In the following sections of this chapter, example applications are provided in order to illustrate the various features of the microcomputer program.

8.2 Example Application 1

A rural segment of a two lane highway passes through level terrain. Fifty percent of traffic is in the opposing direction. Percent trucks and percent RVs are each equal to 10%. Use a PHF of 1.0. Although anticipated DHV for a study horizon of 15 years is 1,500 veh/h, sensitivity analysis is desired for volume levels ranging from 300 veh/h to 1500 veh/h. Assume that DHV is 17.4% of AADT. Passing is allowed throughout the effective distance of a passing lane, tentatively selected to be 8000 m. Design speed is 100 km/h. Study the operational and safety performance, economic feasibility and cost-effectiveness of installing a passing lane at this site.

This example was solved manually and also by the use of the microcomputer program. Here, both outputs are displayed. Due to different levels of significant figures and rounding, answers at times are somewhat different.

Table 8.1 is the screen dump from PCL showing roadway and traffic input characteristics.

8.2.1 Assured Passing Opportunity Warrants

1. Estimate desired assured passing opportunity:

Table 8.1

Roadway and Traffic Inputs

TCL 2.03 - Roadway and Traffic Characteristics

Site ID: **base** Description: **Sensitivity Analysis, Base Run**

GRADES

Terrain Type ? **Level**

Site Length, m
8000

TRAFFIC VOLUME

DHV % of AADT **17.4** %

Case	1	2	3	4
DHV, v/hr	300	500	1000	1500
% Advancing	50.0 %			
% Trucks	10.0 %			
% RV's	10.0 %			
Peak H.F.	1.0			

PASSING ZONES

Passing allowed ? **Yes**
Percent no-passing zones ? **0.0** %

Save ? No

Alt-H Help. F1 Explain. Alt-F1 Keys. Ctrl-F1 About DelSite F10 Menu

$$\text{Desired APO (\%)} = \frac{\text{Passing lane length in km.}}{[(480Q/V_{adv}) + \text{Passing lane length in km.}]}$$

where Q is size of queue (vehicle)
V_{adv} is volume in direction 1
A passing lane length of 1.6 - 2.0 km may be assumed for these calculations.

	Q = 4 vehicles				Q = 6 vehicles			
DHV (veh/h)	300	500	1000	1500	300	500	1000	1500
Desired APO (%)	13.5	20.7	34.2	43.9	9.4	14.8	25.8	34.2

2. Estimate Assured Passing Opportunity (APO) without a passing lane.

Assured passing opportunity (% APO) = [(POSD)x(HF)] x 100

where POSD is the % of the length of road in which passing sight distance requirements are met
HF = is headway factor -- the % of time when headway is equal to or exceeds 25s in the opposing direction-- assuming a design speed of 100 km/h; a time of 25s is required to perform a passing operation (use in fractional terms).

The following table provides HF values.

Direction 2 (i.e., Opposing) Volume, veh/h	50	100	150	200	250	300	350	400	500	550
HF Factor (%)	72	58	48	41	34	28	23	19	16	13
Opposing Vol.	600	650	700	750	800	850	900	950	1000	
HF Factor	9	7.5	6.5	5	3.5	3	2.5	2	1.5	

DHV (veh/h)	300	500	1000	1500
APO (%)	48	34	16	5

3. Compare "desired APO" with "APO without a passing lane". If the desired APO is not met, consider this site for a passing lane.

DHV	300	500	1000	1500
APO desired (%) (i.e., APO with passing lane)				
Q = 4	13.5	20.7	34.2	43.9
Q = 6	9.4	14.8	25.8	34.2
APO provided (%) (without passing lane)	48	34	16	5
APO Criteria met without passing lane?				
Q = 4	Yes	Yes	No	No
Q = 6	Yes	Yes	No	No

Note: For DHVs of more than 500 vehicles/hour, this site may be considered as a candidate for a passing lane.

Table 8.2 shows the results of assured passing opportunity analysis.

8.2.2 Passing Lane Length and Effective Distance

The effective distance could be called the lane frequency distance (LF). As one type of study, establish passing lane length and effective distance by using the existing MTO procedure:

$$LF = = \frac{480\ Q}{V_{adv}} + \text{length of passing lane in km}$$

Answers for an assumed passing lane length of 2.0 km, Q = 4, Q = 6 are shown below. The PCL output that corresponds to the following table is presented as Table 8.3.

DHV (veh/h)	300	500	1000	1500
LF (km)				
Q = 4	14.8	9.7	5.8	4.6
Q = 6	21.2	13.5	7.8	5.8

Table 8.2

Assured Passing Opportunities

Site: base - Sensitivity Analysis, Base Run

ASSURED PASSING OPPORTUNITES: (for lane length of 2.0 km)

DHV (veh/hr)	300	500	1000	1500
Provided APO (%)	48.0	34.0	16.0	5.0
Q = 4 vehicles				
Desired APO (%)	13.5	20.7	34.2	43.9
APO Criteria Met?	Yes	Yes	No	No
Q = 6 vehicles				
Desired APO (%)	9.4	14.8	25.8	34.2
APO Criteria Met?	Yes	Yes	No	No

Some APO criteria are violated when there is no passing lane.

Confirm

Analyse for a Passing Lane ? Yes No

Table 8.3

Passing Lane Length and Effective Distance

Site: base - Sensitivity Analysis, Base Run

Passing Lane Length: **2000 m**
Effective Distance: **8000 m**
Design Speed: **100 km/h**
Average/High Platooning ? Average High

SUGGESTED EFFECTIVE DISTANCES, m:

Values from existing MTO procedures (for lane length of 2000 m):

DHV (veh/hr)	300	500	1000	1500
Q = 4	14800	9700	5800	4600
Q = 6	21200	13500	7800	5800

New suggested values (see Section 7.2 of Report):

Anticipated DHV 15 year horizon	Length of Lane (including tapers)	Effective Distance (also called Lane Frequency, LF)
500 - 700 veh/h	1000 m - 1600 m	13000 m
800 - 1000 veh/h	2000 m	10000 m
Over 1000 veh/h	2000 m	8000 m

At this stage of the analysis, the user is expected to examine results shown above, check the advisory information provided below that has resulted from the present study, and specify LF (i.e., effective distance) and length of passing lane for further calculations.

The following suggested values of passing lane length and effective distance that correspond to various traffic volume levels are based on the findings of this study.

Anticipated DHV 15 year horizon	Length of Lane (including tapers)	Effective Distance (also called Lane Frequency LF)
500 - 750 veh/h	1,000m-1,600m	13,000m
800 - 1000 veh/h	2,000m	10,000m
Over 1000 veh/h	2,000m	8,000m

Use a default value of 2 km for lane length and 8 km for effective distance.

8.2.3 Performance of Passing Lane

For further analyses, a 2000 m passing lane is used in conjunction with an 8,000 m long effective distance. The program uses equations developed in this study to estimate percent of vehicles in platoons (used as an indicator for percent of time vehicles are delayed), average speed, and accidents. The computational procedures described earlier result in delay reduction and accident reduction due to passing lane.

For the estimation of level of service (LOS), use the following criteria for design speed of 100km/h or higher (based on HCM 1985).

Level of Service Criteria

	Level Terrain		Rolling Terrain	
LOS	% Time Delay	Avg. Speed Km/h	% Time Delay	Avg. Speed Km/h
A	≤ 30	≥ 93.4	≤ 30	≥ 91.8
B	≤ 45	≥ 88.6	≤ 45	≥ 86.9
C	≤ 60	≥ 83.7	≤ 60	≥ 82.1
D	≤ 75	≥ 80.5	≤ 75	≥ 78.9
E	> 75	≥ 72.5	> 75	≥ 64.4
F	100	< 72.5	100	< 64.4

The use of equations (based on low platooning and high platooning assumptions) results in estimates of % of vehicles in platoons and average speed. The levels of service are also shown, based on platooning and speed criteria. Table 8.4 presents PCL outputs.

Summary of Results

DHV	300	500	1,000	1,500
AADT	1,724	2,874	5,747	8,621
Platooning without passing lane				
Low platooning equation	28.3%	36.0%	55.1%	74.2%
High platooning equation	34.6	42.1	60.8	79.4
Average	31.5	39.1	58.0	76.8
Level of service (% time delay criterion)	B	B	C	E
Platooning with a passing lane				
Low platooning equation	25.3%	33.3%	53.3%	73.4%
High platooning equation	27.7	35.6	55.4	75.2
Average	26.5	34.5	54.4	74.3
Level of service (% time delay criterion)	A	B	C	D

Table 8.4

Performance of Passing Lane

Passing Lane Length: **2000** m
Effective Distance: **8000** m
Design Speed: **100** km/h
Average/High Platooning ? **Average**

SUMMARY OF RESULTS:

DHV	300	500	1000	1500	veh/h
AADT	1724	2874	5747	8621	veh/day
% Time Delay, No Lane	31.5	39.0	57.9	76.8	%
Level of Service, No Lane	B	B	C	E	
% Time Delay, With Lane	26.5	34.4	54.4	74.3	%
Level of Service, With Lane	A	B	C	D	
Average Speed, No Lane	93.4	91.3	86.1	80.9	km/h
Level of Service, No Lane	A	B	C	D	
Average Speed, With Lane	94.4	92.5	87.7	82.8	km/h
Level of Service, With Lane	A	B	C	D	
Delay reduction	591	1173	3439	7184	veh-hrs/yr
Accident reduction	1.15	2.19	5.73	10.64	acc./yr

Summary of Results (Cont.)

DHV	300	500	1,000	1,500
AADT	1,724	2,874	5,747	8,621
Average speed without passing lane				
Low platooning equation	94.7 km/h	92.5 km/h	87.3 km/h	81.7 km/h
High platooning equation	92.0	90.1	85.0	80.0
Average of two equations	93.4	91.3	86.2	80.9
LOS without a passing lane (speed criterion)	A	B	C	D
Average speed with passing lane				
Low platooning equation	95.4 km/h	93.5 km/h	88.6 km/h	83.7 km/h
High platooning equation	93.4	91.5	86.8	82.1
Average of two equations	94.4	92.5	87.7	82.9
LOS with a passing lane (speed criterion)	A	B	C	D

The next step was to compare performance of two lane highway section with and without passing lane in terms of change in travel time and reduction of accidents. Results are shown below and also in Table 8.4.

DHV AADT	300 1,724	500 2,874	1000 5,747	1500 8,621
Change in travel time/year due to passing lane (hrs) (i.e., veh. hrs saved/yr)	571	1,192	3,330	7,507
Change in accident involvement rate/ 100 m veh-km	22.09	26.50	33.13	44.17
For 8 km section of roadway, million veh-km/year	5.03	8.39	16.78	25.17
Reduction in accident involvements/year	1.11*	2.22	5.56	11.12

* [(22.09/100)x(5.03) = 1.11

8.2.4 Cost-Effectiveness

To begin with, the following measures were used separately:

. Reduction in travel time (hours/year)
. Reduction in accident involvement rate (accident involvement /100 million veh-km).

DHV AADT	300	500	1000	1500
Change in travel time (hrs/year)	571	1,192	3,330	7,507
Change in travel time (min/100 vehicles)	5.4*	6.8	9.5	14.3
Reduction in accident involvement rate/100 m veh-km	22.09	26.50	33.13	44.17

* [(571 x 60)/(365x1,724)]x100=5.4

Following a study of single measures of effectiveness, multiple measures were investigated:

. Measures: Travel Time/Delay reduction DR, Accident reduction AR

. Relative Values: Transform DR & AR into relative values.

DHV AADT	300	500	1000	1500
Travel time reduction (hrs/year	571	1,192	3,330	7,507
Relative value for travel time reduction*	0.08	0.16	0.44	1.0
Reduction in accident involvements/yr	1.11	2.22	5.56	11.12
Relative value for accident involvement reduction*	0.10	0.20	0.50	1.0

* Procedure:

For all alternatives (in this case only one alternative with various DHV's), identify the highest value of effectiveness measure. Set it equal to 1 (the highest value on the 0 to 1 relative value scale). Find the remaining values by taking ratios -- e.g., set 7,507 hrs/yr = 1. Then the relative value for 3,788 hrs/yr = (1/7,507) x 3,330 = 0.44.

A weighting of effectiveness measures was carried out next. The following user specified weights were used.

Example Measure	Weights (w)
DR Delay reduction	0.4
AR Accident reduction	0.6
	1.0

Weighted Effectiveness

DHV	Weighted Effectiveness*
300	(0.4)(0.08) + (0.6)(0.10) = 0.09
500	(0.4)(0.16) + (0.6)(0.20) = 0.18
1000	(0.4)(0.44) + (0.6)(0.50) = 0.48
1500	(0.4)(1.00) + (0.6)(1.00) = 1.00

* General formula:
  Weighted effectiveness of an alternative =
  (weight for delay reduction)(relative value for delay reduction)
+ (weight for accident reduction)(relative value for accident reduction)

For the estimation of economic feasibility of the passing lane option, inputs for economic feasibility were specified. The procedure followed has been described in Chapter 8.

Base year is 1989

Benefit measures:
- travel time saving/delay reduction
- reduction in accident involvement rate

Real rate of return i = 5% for the case of "discounting of benefits"
i = 0% for the case of "no discounting of benefits"

Inflation f = 5%
N = 30 years
VT (in constant dollars of 1989) = $5/h
VAC (in constant dollars of 1989)* = $ 5000 for property damage/accident + $ 5000 (for injury, fatality)/accident
= $10,000/accident

* Notes: 1987, Ontario [32]:
  21,235 accidents reported for "other King's" Highways
  402 fatalities reported for these highways
  14,735 persons were injured on these highways
  $5000/accident (avg.) for property damage
  1 fatality for 52.82 accidents
  1 injury for 1.44 accidents

Cost of passing lane was calculated on the basis of the procedure described in Chapter 7 and the following input information.

. Cost of passing lane/km (1989$) = $396,000/km
. Maintenance cost/km (1989$) = 0 (assumed in this example)
. Total cost/km = $396,000 + $0 + $396,000/km
. Cost of passing lane (in constant $ of 1989)/yr =
  [2.0 km x $396,000]/30 = $26,400/yr

Estimate economic feasibility of each alternative was found in accordance with the principles and methodology explained in Chapter 7.

DHV	300	500	1,000	1,500
AADT	1,724	2,874	5,747	8,621
Without discounting of benefits:				
Benefits due to time saving/yr (1989 const. $)	2,855	5,960	16,650	37,535
Safety benefits/yr (1989 const. $)	11,100	22,200	55,600	111,200
Total benefits/yr (1989 const. $)	13,955	28,160	72,250	148,735
Cost/yr (1989 const. $)	26,400	26,400	26,400	26,400
Net benefits/yr (1989 const. $)	-12,445	1,760	45,850	122,335
With discounting of benefits:				
Benefits due to time savings/yr (1989 const. $)	1,463	3,054	8,532	19,233
Safety benefits/yr (1989 const. $)	5,694	11,389	28,490	57,046
Total benefits/yr (1989 const. $)	7,157	14,443	37,022	76,279
Net benefits/yr. (1989 const. $)	-19,243	-11,957	10,622	49,879

The cost-effectiveness results are presented below.

DHV	300	500	1,000	1,500
AADT	1,724	2,874	5,747	8,621
Cost/100 vehicles (1989 $)	4.20	2.52	1.26	0.84
Cost/100 veh-km (1989 $)	0.53	0.31	0.16	0.10
Cost-Effectiveness				
$ of cost/veh-hr saved	46.23	22.15	7.93	3.52
$ of cost/accident involvement reduction	23,784	11,892	4,748	2,374

The results of effectiveness, economic feasibility and cost-effectiveness analyses obtained from the PCL program, that correspond with the above results, are presented in Table 9.5. Due to programming efficiency the order of presentation of information in Table 8.5 is not the same as shown above.

A comparison of manual computations with the PCL program outputs indicates that the program is producing correct results. Results of example application 1 suggest the following conclusions.

- On the basis of MTO's assured passing opportunity criterion, a passing lane should be considered for DHVs higher than 500.
- According to MTO's existing method, a lane frequency of about 8000 m would be required for DHV of 1000 and less than 6000 m for DHV of 1500 m.
- According to guidelines suggested on the basis of this study, the following combinations of lane length and effective distance would be appropriate for the initial design of passing lane:
  - For a DHV of 800-1000, try 2000 m lane and 10,000 m effective distance.
  - For a DHV of over 1000, try 2000 m lane and 8,000 m effective distance.

Table 8.5

Cost-Effectiveness of Passing Lane

PCL 2.03 - Effectiveness Measures

Mon Jun 10 06:51:12 1991

Site: base Sensitivity Analysis, Base Run

WEIGHTS
- Delay Reduction: 0.40
- Accident Reduction: 0.60

COST DATA
- Base Year: 1989
- Real Rate of Return: 5.00 %
- Facility Life: 30 yr
- Vehicle Hour Cost: 5.00 $
- Vehicle Acc. Cost: 10000 $
- Lane Unit Cost: 396000 $/km
- Maintenance Cost: 0 $/km/yr

SINGLE EFFECTIVENESS MEASURES: (Effective Distance = 8.00 km)

DHV	300	500	1000	1500	veh/hr
AADT	1724	2874	5747	8621	veh/day
Delay Red.	5.6	6.7	9.8	13.7	min/100 veh

Alt-H Help. F1-Explain. Alt-F1 Keys. Ctrl-F1-About EffMeas F10-Menu

Table 8.5 (Cont.)

Cost-Effectiveness of Passing Lane

PCL 2.03 - Effectiveness Measures

Delay Red.	5.6	6.7	9.8	13.7	min/100 veh
Acc. Red.	0.23	0.26	0.34	0.42	acc/M veh-km

MULTIPLE EFFECTIVENESS MEASURES:

DHV	300	500	1000	1500	veh/hr
Delay Red.	0.082	0.163	0.479	1.000	relative
Acc. Red.	0.108	0.206	0.539	1.000	relative
Weighted Eff.	0.098	0.189	0.515	1.000	

COSTS OF ADDING PASSING LANE:

Lane Length = 2.00 km Roadway Length = 8.00 km
Lane Construction Cost = 396000 $/km
Lane Maintenance Cost = 0 $/km/yr

Total Lane Construction Cost =	792000 $ =	26400	$/yr
Total Lane Maintenance Cost	=	0	$/yr
TOTAL LANE COST	=	26400	$/yr

BENEFITS FROM ADDING PASSING LANE:

Alt-H-Help. F1-Explain. Alt-F1-Keys. Ctrl-F1-About EffMeas F10-Menu

Table 8.5 (Cont.)

Cost-Effectiveness of Passing Lane

BENEFITS FROM ADDING PASSING LANE:					
DHV	300	500	1000	1500	veh/hr
Delay Red.	590.6	1173.3	3438.9	7183.8	hr/yr
Acc. Red.	1.15	2.19	5.73	10.64	acc/yr
Without discounting of benefits:					
DR Benefits	2953	5866	17195	35919	1989$/yr
AR Benefits	11500	21880	57330	106360	1989$/yr
Total Benefits	14453	27746	74525	142279	1989$/yr
Net Benefits	-11947	1346	48125	115879	1989$/yr
With discounting of benefits using a 5.00% real rate of return:					
DR Benefits	1513	3006	8811	18405	1989$/yr
AR Benefits	5893	11212	29377	54500	1989$/yr
Total Benefits	7406	14218	38188	72906	1989$/yr
Net Benefits	-18994	-12182	11788	46506	1989$/yr
COST-EFFECTIVENESS VALUES:					
DHV	300	500	1000	1500	veh/hr
AADT	1724	2874	5747	8621	veh/day
Annual Cost	26400	26400	26400	26400	1989$/yr

Table 8.5 (Cont.)

Cost-Effectiveness of Passing Lane

PCL 2.03 - Effectiveness Measures

COST-EFFECTIVENESS VALUES:					
DHV	300	500	1000	1500	veh/hr
AADT	1724	2874	5747	8621	veh/day
Annual Cost	26400	26400	26400	26400	1989$/yr
Cost	4.20	2.52	1.26	0.84	1989$/100 veh
Cost	0.52	0.31	0.16	0.10	1989$/100 veh-km
Effectiveness: Single Measures					
Delay Red.	591	1173	3439	7184	hr/yr
Delay Red.	5.63	6.71	9.84	13.70	min/100 veh
hr/$	0.02	0.04	0.13	0.27	veh-hr/1989$
$/hr	44.70	22.50	7.68	3.67	1989$/veh-hr
Acc. Red.	1.1	2.2	5.7	10.6	acc/yr
Acc. Red.	0.23	0.26	0.34	0.42	acc/M veh-km
acc red/$M	43.56	82.88	217.16	402.88	acc red/M1989$
$cost/acc red	22957	12066	4605	2482	1989$/acc red
Weighted Eff.	0.098	0.189	0.515	1.000	

Alt-H-Help, F1-Explain, Alt-F1-Keys, Ctrl-F1-About EffMeas F10-Menu

- The level of service of the highway section without a passing lane (based on % time delay criterion) falls to C at DHV of 1000 and becomes E at DHV of 1500. The provision of a passing lane improves the level of service.

- As expected, delay reduction, accident reduction and combined measures improve with increasing DHVs.

- With discounting of benefits at a 5% real rate of return, a passing lane becomes feasible at DHVs between 500 and 1000. With no discounting of benefits, the passing lane is feasible at 500 veh/h.

- The $ cost/hour of delay reduced (in 1989 $) drops from $44.70 for DHV of 300 to only $3.67 when DHV becomes 1500.

- The $ cost/accident reduced (in 1989$) is only $4,605 at DHV of 1000 and $2482 for DHV of 1500.

8.3 Example Application 2: Optimal Length of Passing Lane

The objective of this second example application was to establish the most desirable length of passing lane for the site covered in Example Application 1. Three passing lane lengths, namely 1 km, 2 km, and 3 km were investigated while keeping the effective distance of 8 km and other features fixed. Results are shown in Table 8.6.

Interesting observations can be drawn from results presented in Table 8.6.

- In economic efficiency terms, as measured by net benefits with discounting of benefits, the 2 km long passing lane is the best choice for DHV of 1000 and higher volumes. For DHVs of 300 and 500, the 1 km option offers the highest net benefits (with discounting). The 3 km long passing lane is the worst choice for all levels of traffic.

- In terms of $/accident reduced and also $/hour of time saved, the 1 km and 2 km long lanes are more cost-effective than 3 km lane.

- The obvious conclusion to be drawn from this example application is that 2 km or shorter lanes are desirable in economic efficiency and cost-effectiveness terms. There is nothing more to be gained in economic efficiency terms by providing a 3 km lane as opposed to a 2 km lane.

Table 8.6

Cost-Effectiveness of Passing Lane Lengths of 1, 2 & 3 Kms

Case 1: 1000 m Lane, 8000 m Effective Distance				
DHV	300	500	1000	1500
Net benefit with discounting ($)	-9,693*	-5,536*	11,562	39,011
$/accident reduced	24,265	11,205*	3,556*	1,736*
$/hour of delay reduced	47.00	20.78*	5.89*	2.55*
Case 2: 2000 m Lane, 8000 m Effective Distance				
DHV	300	500	1000	1500
Net benefit with discounting ($)	-18,994	-12,182	11,788*	46,506*
$/accident reduced	22,857*	12,066	4,605	2,482
$/hour of. delay reduced	44.70*	22.50	7.68	3.67
Case 3: 3000 m Lane, 8000 m Effective Distance				
DHV	300	500	1000	1500
Net benefit with discounting ($)	-29,915	-21,555	6,428	45,377
$/accident reduced	26,312	14,250	5,726	3,191
$/hour of delay reduced	51.42	26.66	9.58	4.74

For other input data, please Example Application 1.
* Best result for given DHV level.

8.4 Example Application 3: Climbing Lane

The methodology for the climbing lane module has been described in references 2 and 3. Here, the intent is to give a brief introduction to this module and to show an example application.

Inputs are to be specified in terms of roadway and traffic characteristics. The following are the information items and their format.

- Grades, length of grades
- Passing allowed/passing not allowed
- Traffic volume:
  Design hour volume (DHV)
  Average Annual Daily Traffic (AADT)
- Directional split:
  Uphill direction = Direction 1
  Downhill direction = Direction 2
- Percent trucks
- Percent recreational vehicles (RVs)
- Peak Hour Factor (PHF)

The traffic volume level should not fall outside the range of 300-1500 veh/h. The equations developed for use in this program were based on the 300-1500 veh/h range. Given that the PCL methodology was developed for the analysis and evaluation of auxiliary lanes, this range of traffic volume is very appropriate.

It is to be noted that since the program was developed for the analysis and evaluation of climbing lane options, the traffic level to be used should not fall outside the range of traffic used for the development of equations incorporated in the PCL program -- i.e., 300-1,500 vehicles per hour.

The program accepts inputs for one candidate site for one cycle of program use. Multiple sites should be handled separately and results could be compared.

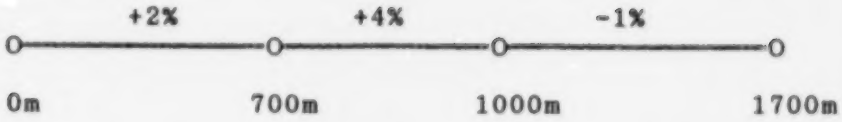
Grades could be specified in a variety of fashion, depending upon terrain. Positive grade(s) are to be checked in order to establish whether to use:

- average grade (for composite positive grades), or
- individual grade.

Guidelines for the choice of method are based on HCM (1985). If no single grade exceeds 4% or total length of composite (positive) grade does not exceed 1220m, average grade may be used for the study of truck speed drop upgrade.

Case 1:

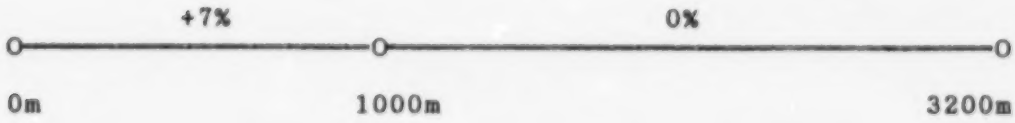
Here, use average grade:



Total rise = 700x2 + 300x0.04 = 26m
Average (up) grade = (26/1000)x100 = 2.6%

Case 2:

In the case noted below, use 7% as the upgrade up to 1000m distance.



Passing (overtaking) information is to be specified in terms of:

. overtaking allowed (i.e., 0% no passing zones)
. overtaking not allowed (i.e., 100% no passing zones).

Intermediate values of "percent no passing zones" may also be specified.

The DHV is specified as a percent of AADT. For example, DHV = 19.4% of AADT.

Traffic composition has to be provided as an input to the program. Percent trucks and % RVs are to be provided by the user.

Heavy truck selection is permitted. Two options are 180 kg/kw and 120 kg/kw.

Two options are available for treating climbing lane length and location. In one case, a computerized determination of climbing lane length and location could be carried out. The program offers the choice of truck type (180 kg/kw and 120 kg/kw). The automated determination of climbing lane geometry is based on the criterion of a 15 km/h speed drop for starting a climbing lane and ending the climbing lane beyond crest where the

design truck regains speed such that its speed is within 15km/h difference.

The approach speed for the heavy truck can be set equal to or less than 90 km/h for climbing lane design. It should be noted that under high volume conditions, approach speed of 90 km/h may be difficult to attain (at 0% grade). On the other hand, under very low traffic and very favourable sight distance conditions, a truck of 120 kg/kw may attain approach speeds of 100 km/h. Even the 180 kg/kw truck can attain 93.8 km/h speed on level grade. Here, the intent is not to find various lengths of climbing lanes that correspond to different approach speeds. In order to reduce the number of climbing lane lengths to be analyzed, it is assumed that the heavy truck selected will enter the upgrade section at the posted speed of 90 km/h.

The computer program estimates the speed of heavy truck at various locations along the positive grade. For example, for a single grade, it uses the speed-distance tables (curves) that yield "deceleration upgrade". Speed at crest is found first. Next, this speed is used by the program as the starting point for the use of table (curve) marked "acceleration on level road or downgrade. The computer program finds the location where the speed of truck drops 15 km/h below the highway speed (i.e., 75 km/h) and that location where the truck regains speed to the 75 km/h level. These locations are the beginning and the ending points of the truck climbing lane.

The length of climbing lane is approximated by tangents rather than the length of vertical curves. Transition distance is in part included in the estimation of climbing lane. If the estimated climbing lane is less than 1500m, a length of 1500m is used (including transition distance.

In the second option, the user may wish to specify the geometric features of the climbing lane. For a number of reasons, such as topography, a designer may wish to deviate from the above noted procedure which results in taking the climbing lane beyond crest. The analyst may start the climbing lane at the beginning of the upgrade section and end it near the crest or at crest. The computer program requires inputs on the starting and ending points of the climbing lane.

The next part of the program is devoted to the estimation of climbing lane performance in terms of level of service and speed. The information generated by this module enables the checking of warrants in terms of truck climbing performance and level of service drop. Accident reduction information is also displayed.

For the estimation of approach speed and level of service (LOS), the assumption of 100 km/h design speed is made. However,

90 km/h design speed could also be assumed since the program has built-in guides applicable to both design speed levels. This part of the program uses the HCM (1985) procedures for level terrain. The methodology for such calculations is discussed in detail in Chapter 4 of reference 2.

The final part of this module is devoted to the estimation of effectiveness measures for each alternative. Two different types of effectiveness studies can be carried out. Single measures of effectiveness can be quantified for a number of alternatives or for various traffic levels for one site. The effectiveness measures used are: reduction in delay and reduction in accident involvement rate.

The cost of climbing lane is calculated and computations are carried out for assessing the economic feasibility of alternatives and sensitivity tests. The procedures for calculating the cost-effectiveness of alternatives and sensitivity analysis are similar to those for the passing lane case. Theoretical aspects of these methods for evaluation of climbing lane alternatives are covered in Chapter 4 of reference 2. The following example application provides details of computational steps involved.

Problem Statement

A rural segment of a two lane highway has a 1 km long 7% grade, preceded by as well as followed by level terrain. Check the fulfillment of warrants for a climbing lane. Also, study the cost-effectiveness as well as economic feasibility of a climbing lane for DHV levels that range from 300 to 1500. Percent traffic in the upgrade direction is 50%. Percent trucks and % RVs are each equal to 10%. Use a PHF of 1.0. Estimate performance under the assumption of overtaking allowed. Also show selected answers for overtaking not allowed. The weight/power ratio of the design truck is 180 kg/kw.

This example was solved manually and also by the use of the microcomputer program. Here, both outputs are displayed. Due to inconsistencies in the HCM (1985) figures, different levels of significant figures and rounding, answers at times are somewhat different.

The roadway and heavy truck data were used to manually estimate the length and location of climbing lane. A climbing lane of about 2000m is required, starting 200m from the beginning of upgrade section.

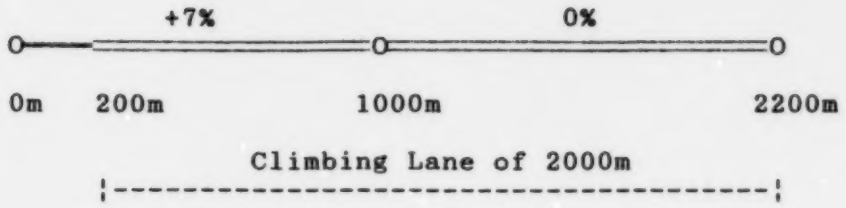


Table 8.7 is a screen dump from PCL showing roadway and traffic input characteristics. Table 8.8 shows the results of the computerized technique for determining climbing lane length and location. The starting point for the climbing lane is 149m and the length is 2014m.

Approach Speed & Level of Service: "Overtaking Allowed"

The methodology developed in this study was used as a basis for the estimation of various indicators of performance for the roadway under study.

Example:

Average approach speed = 90 km/h
$(v/c)_B$ = 0.27 for LOS B (Table 4.1 of reference 2)
f_d = 1.0 (Table 4.2 of reference 2)
f_w = 1.0 (Table 4.3 of reference 2)
E_T = 2.2 (Table 4.4, LOB B of reference 2)
E_R = 2.5 (Table 4.4, LOS B of reference 2)
P_T & P_R = 0.1 (given)
f_{HV}(LOS B) = 0.79 (Equation noted in Chapter 4 of reference 2)
$SF_{LOS\,B}$ = 597 vph (Equation noted in Chapter 4 of reference 2)

The answers for various speeds & LOS are shown below.

Avg. Approach Speed (km/h)	93.4	90	84	80	72
LOS	A	B	C	D	E
SF (veh/h)	344	597	951	1541	2408

For given DHVs, find approach speed first, by taking into account the effect of peaking within the hour.

Two-way volume/h = DHV/PHF
For PHF =1.0, the DHVs are equal to volume estimates.

Table 8.7

Roadway and Traffic Inputs

PCL 2.05 - Roadway and Traffic Characteristics

Site ID: **example3** Description: **Example from final report**

GRADES

Terrain Type ? **Hilly**

Distance, m	Grade, %
0	
	7.0
1000	
	0.0
2200	

TRAFFIC VOLUME

DHV % of AADT 17.4 %

Case	1	2	3	4
DHV, v/hr	300	500	1000	1500
% Advancing	50.0 %			
% Trucks	10.0 %			
% RV's	10.0 %			
Peak H.F.	1.0			

TRUCKS

Truck Weight: 180 kg/kw

PASSING ZONES

Passing allowed ? **Yes**

Percent no-passing zon

Confirm

Site data has been changed. Save changes ? Yes No

Alt-H Help. F1 Explain. Alt-F1 Keys. Ctrl-F1 About DefSite F10 Options

Table 8.8

Determination of Climbing Lane Length

```
                    PCL 2.05 - Define Climbing Lane Geometry
Site: example3      Description: Example from final report
                                                 Mon Oct 28 22:15:53 1991
  Distance, m  Grade, %          Truck Size:              180 kg/kw
  --------     -----             Truck Entry Speed:        90 km/h
       0                         Minimum Truck Speed:      75 km/h
                  7.0            Minimum Lane Length:    1500 m
    1000
                  0.0                    Action Selection
    2200                           Q. Quit
                                   1. Enter Design Data and Compute
                                   2. Compute Lane Locations
                                   3. Input Lane Locations
                                   4. View Results
                                   5. Plot Results
  CLIMBING LANE                    6. Save Results

    Locations computed usi  Use truck speed drop to compute locations
    truck speed differenti
    Start, m    End, m  Length, m
       149      2163       2014

Alt-H Help, F1 Explain, Alt-F1-Keys, Ctrl-F1 About DetCL                F10 Menu
```

Approach speed is estimated by comparing volume with service flows (SFs) found earlier. Interpolation may be required. For example, for 300 veh/h, use 93.4 km/h and for 500 veh/h, interpolate.

Overtaking Allowed (0% no passing zones)				
DHV	300	500	1000	1500
Approach Speed (km/h)	93.4	91.3	83.7	80.3
LOS (design speed 100 km/h) (From Table 4.1 of reference 2)	A	B	D	D
LOS (design speed of 90 km/h) (See footnote to Table 4.1 of reference 2)	A	A	B	C
LOS (use of upgrade speed and LOS criteria, Table 4.5 of ref. 2)*	A	A	B	B

* Note: These are used in the program for approach LOS.

The reader may wish to note that in the estimation of level of service as illustrated above, for higher DHVs (e.g., 1500), the use of upgrade section LOS criteria shows a better LOS (i.e., C) than those obtained from the use of level grade criteria (i.e., D for 100 km/h design speed). This serves to illustrate the inconsistency in the guidelines provided in Chapter 8 of HCM (1985). Similar observations were made by other authors. Conceptually, a highway cannot have a better LOS upgrade than level approach.

Approach Speed & LOS: Overtaking Not Allowed (100% No Passing Zones)

Example:
Average speed = 90 km/h: $(v/c)_B = 0.16$
$f_d = 1.0$
$f_w = 1.0$
$E_T = 2.2$ (for LOS B)
$E_R = 2.5$ (for LOS B)
P_T & $P_R = 0.1$

f_{HV} (LOS B) = 0.79
$SF_{LOS\,B}$ = 354 vph

Approach Speed* (km/h)	>93.4	>90	>84	>80	>72
LOS	A	B	C	D	E
SF (veh/h)	92	354	708	1372	2408

* Based on design speed of 100 km/h.

As in the case of overtaking allowed, we can find approach speed and LOS for various DHVs. However, these computations were not carried out.

Upgrade Speed & Delay "Without Climbing Lane"

From the use of relations and tabular information presented in Chapter 4 of reference 2, various indicators of operational efficiency are found for a 1000m long upgrade section with a +7% grade. Intermediate steps are shown here as well, when relevant.

Speed (km/h)	90	85	80	72	64	48
E (found by interpolation)	11.04	7.32	5.20	3.72	3.13	2.69

P_0 = 0.8 (given)
$P_{HV} = P_T + P_R = 0.1 + 0.1 = 0.2$
$P_{T/HV} = P_T/P_{HV} = (0.1/0.2) = 0.5$
$I_P = 0.02(E-E_0)$
$f_g = 1/[1 + P_P I_P]$; $P_P = 0.8$
$E_{HV} = 1 + (0.25+P_{T/HV})(E-1)$; $P_{T/HV} = 0.5$
$f_{HV} = 1/[1+P_{HV}(E_{HV}-1)]$; $P_{HV} = 0.2$

Speed (km/h)	90	85	80	72	64	48
I_P	0.179	0.110	0.072	0.046	0.037	0.028
f_g	0.87	0.92	0.95	0.96	0.97	0.98
E_{HV}	8.53	5.74	4.15	3.04	2.60	2.27
f_{HV}	0.40	0.51	0.61	0.71	0.76	0.80

Next, compute total two-way service flow rates for designated speeds.

Speed	2,800 x	v/c	x	f d x	f_w	x	f_g	x	f_{hv}	=	SF
Overtaking Allowed (0% No Passing Zones)											
90		0		1.0	1.0		0.87		0.40		0
85		0.13		1.0	1.0		0.92		0.51		171
80		0.34		1.0	1.0		0.95		0.61		552
72		0.77		1.0	1.0		0.96		0.71		1470
64		0.93		1.0	1.0		0.97		0.76		1920
48		1.00		1.0	1.0		0.98		0.80		2195
Overtaking Not Allowed (100% No Passing Zones)											
90		0		1.0	1.0		0.87		0.40		0
85		0.04		1.0	1.0		0.92		0.51		53
80		0.12		1.0	1.0		0.95		0.61		195
72		0.35		1.0	1.0		0.96		0.71		668
64		0.59		1.0	1.0		0.97		0.76		1218
48		0.86		1.0	1.0		0.98		0.80		1880

Now we can find speed & LOS that correspond to DHVs of interest. Interpolations can be carried out to find speed for given DHVs.

The procedure to be used is as follows. For DHV values, find corresponding volumes by taking into account the PHF (i.e., volume = DHV/PHF). Next compare the resulting volumes with the SF as shown above. Interpolate if necessary and infer the speed. From speed, LOS can be inferred.

DHV	Volume for Comparison Purposes (veh/h)	Upgrade Speed (km/h)	LOS*
Overtaking Allowed, Without Climbing Lane (0% No Passing Zones)			
300	DHV/PHF = 300/1.0+ = 300	83.3	B
500	500/1.0 = 500	80.5	B
1000	1000/1.0 = 1000	76.1	C
1500	1500/1.0 = 1500	71.5	D

* LOS Criteria for Specific Grades
\+ PHF = 1.0

DHV	Volume for Comparison Purposes (veh/h)	Upgrade Speed	LOS*
Overtaking Not Allowed, Without Climbing Lane (100% No Passing Zones)			
300	DHV/PHF = 300/1.0+ =300	78.2	C
500	500	74.8	C
1000	1000	67.2	D
1500	1500	57.3	E

* LOS Criteria for Specific Grades
\+ PHF = 1.0

LOS	A	B	C	D	E
Average Upgrade Speed (Km/h)	>90	80-89	72-79	64-71	<64 & >40

Note: HCM (1985) does not specify whether these apply to highways with 90 km/h design speed or 100 km/h of design speed or both.

Upgrade Speed "With Climbing Lane"

The case of climbing lane ending beyond crest is to be pursued here.

DHV vph	Upgrade Avg. Speed: Without Climbing Lane* km/h	Upgrade Avg. Speed: With Climbing Lane* km/h	Change in Upgrade Avg. Speed* km/h	Upgrade Avg. Speed Without Climbing Lane+ km/h
300	70.8	86.2	15.4	83.3
500	67.6	84.2	16.6	80.5
1000	59.6	79.1	19.5	76.1
1500	51.6	74.0	22.4	71.5

* Use of regression equations (reference 2).
\+ HCM (1985) procedure as described above.

Estimation of Upgrade Average Speed.

DHV vph	Approach Speed km/h	Avg. Upgrade Speed Without Climbing Lane* km/h	Estimated Increase in Speed Due to Climbing Lane km/h	Estimated Upgrade Avg. Speed With Climbing Lane	
				Trial 1 km/h	Final trial+ km/h
300	93.4	83.3	15.4	98.7	89.0
500	91.3	80.5	16.6	97.1	89.0
1000	83.7	76.1	19.5	95.6	83.7
1500	80.3	71.5	22.4	93.9	80.3

* Use of HCM (1985) procedures as described above.
+ See Figure 4.2 of reference 2.

Display of Answers: Overtaking Allowed.

DHV	Approach Speed & LOS		Avg. Upgrade Speed & LOS Without Climbing Lane		Avg. Upgrade Speed & LOS With Climbing Lane	
vph	km/h	LOS	Km/h	LOS	Km/h	LOS
300	93.4	A	83.3	B	89.0	B
500	91.3	A	80.5	B	89.0	B
1000	83.7	B	76.1	C	83.7	B
1500	80.3	B	71.5	D	80.3	B

Delay associated with each case was calculated and reduction in delay due to climbing lane was estimated. Results are presented in a tabular form on the following page.

DHV	300	500	1000	1500
AADT	1724	2874	5747	8621
No Climbing Lane, Overtaking Allowed				
Approach Speed (km/h)	93.4	91.3	83.7	80.3
Upgrade Avg. Speed (km/h)	83.3	80.5	76.1	71.5
Delay/veh. (sec)	10.3	11.6	9.4	12.1
Total Delay/Yr. (Hrs.)	900	1690	2739	5288
With Climbing Lane, Overtaking Allowed				
Upgrade Avg. Speed (km/h)	89.0	89.0	83.7	80.3
Delay/veh (sec)	4.2*	2.2*	0*	0*
Total Delay/Yr. (Hrs)	367	321	0	0
Reduction in Delay/Yr (Hrs)	533	1369	2739	5288

* The trend and these numbers reflect approach speed & upgrade avg. speed.

Summary of Level of Service Computations
(Required for checking warrants for the provision of a climbing lane)

DHV	300	500	1000	1500
AADT	1724	2874	5747	8621
Approach LOS	A	A	B	B
Upgrade LOS Without Climbing Lane	B	B	C	D
Upgrade LOS With Climbing Lane	B	B	B	B

Accident reduction estimates can now be developed that are attributable to the presence of a climbing lane.

Reduction in Accident Involvement Rate

DHV	300	500	1000	1500
AADT	1724	2874	5747	8621
Approach Speed (km/h)	93.4	91.3	83.7	80.3
Upgrade Operating Speed Without Climbing Lane (km/h)	83.3	80.5	76.1	71.5
Speed Reduction Upgrade Without Climbing Lane (km/h)	10.1	10.8	7.6	8.8
Accident Involvement Rate Without Climbing Lane (Acc./100m veh-km)	355.50	370.96	300.29	326.79
Upgrade Operating Speed With Climbing Lane (km/h)	89.0	89.0	83.7	80.3
Speed Reduction With Climbing Lane (km/h)	4.4	2.3	0	0
Accident Involvement Rate With Climbing Lane (Acc./100m veh-km)	229.62	183.24	132.44	132.44
Reduction in Accident Involvement Rate (Acc./100m veh-km)	125.88	187.72	167.85	194.35

Accident reduction per year is to estimated for cost-effectiveness study.

Roadway length = 2.2 kms (from the approach to the end of climbing lane)				
DHV	300	500	100	1500
AADT	1724	2874	5747	8621
Million Veh-km/Yr	1.38	2.31	4.61	6.92
Accident Involvements/ Yr. Without Climbing Lane	4.9	8.6	13.8	22.6
Accident Involvements/ Yr. With Climbing Lane	3.2	4.2	6.1	9.2
Reduction in Accident Involvements/ Year	1.7	4.4	7.7	13.4

Note: For "Other King's" Highways, in 1987

- one fatality for 52.82 accidents
- one injury for every 1.44 accidents
- average of $5,000/accident for "property damage"

Source for accident statistics: Reference [32].

Warrants for the provision of a climbing lane can now be checked.

Climbing Lane Warrants
Case: Overtaking Allowed

DHV	300	500	1000	1500
AADT	1724	2874	5747	8620
Heavy Truck Speed Reduction > 15 km/h*	Yes	Yes	Yes	Yes
Drop in LOS Upgrade+	No	No	Yes	Yes

* For increased safety and avoiding unreasonable delays caused by heavy vehicle performance on grade, the speed reduction criterion is 15 km/h (applies to heavy truck).

+ Whenever there is a drop of one or more levels of service upgrade vs. the design LOS of B for the highway, a climbing lane should be considered for that site.

Note that safety warrants are not defined directly. However, in an indirect manner, safety is included in heavy truck speed reduction criterion.

At this stage in describing the case study, it would be useful to show outputs from the PCL program. Table 8.9 shows user-specified climbing lane geometry. Table 8.10 is a screen dump summarizing performance estimates and results of a check on warrants.

Cost-Effectiveness and Economic Feasibility

The effectiveness of the climbing lane case is to be investigated for DHVs of 300, 500, 1000, and 1500. Initially, single measures are to be examined. Multiple measures are studied jointly. Economic feasibility of a climbing lane section in benefit-cost terms and the cost-effectiveness of the climbing lane are investigated. Estimates of performance indicators are based on the assumption that overtaking is allowed.

Table 8.9

User Specified Climbing Lane Geometry

Site: example3 Description: Example from final report

Mon Oct 28 22:11:16 1991

Distance, m	Grade, %
0	
	7.0
1000	
	0.0
2200	

Truck Size: 180 kg/kw
Truck Entry Speed: 90 km/h
Minimum Truck Speed: 75 km/h
Minimum Lane Length: 1500 m

CLIMBING LANE

Locations input by user:

Start, m	End, m	Length, m
200	2200	2000

Table 8.10

Climbing Lane Performance Estimates

```
Site: example3 - Example from final report

 Design Speed:  100 km/h
 Lane Width: 3.66m
 Shoulder Width: >= 1.83m
 Effective Distance
    Beyond End of Lane:      0 m

   DHV                  300        500       1000       1500  veh/h
   Approach          92.5 A     90.0 A     84.1 B     80.8 B  km/h LOS
   Up Avg NoCL       83.1 B     81.0 B     76.6 C     72.0 D  km/h LOS
     With CL         89.0 B     89.0 B     84.1 B     80.8 B  km/h LOS
   Delay Red.         549.6     1278.9     2718.1     5239.5  hrs/yr
   Acc. Red.            1.8        4.1        7.7       13.5  accidents/yr
   TRUCK WARRANT          ?          ?          ?          ?
   LOS WARRANT           No         No        Yes        Yes
                  'Yes' means that a climbing lane is required.
                  Truck speeds have not been calculated.

   NOTES:
      - Delay Reductions are for upgrade traffic only (50% of total)- Benefits
 computed over an effective distance of 2200 m
```

Reduction in Delay (hrs/yr)

DHV	300	500	1000	1500
Reduction in Delay/Yr (hrs/yr)	533	1369	2739	5288
Delay Reduction minutes/ 100 vehicles	5.1	7.9	7.9	10.1

Reduction in Accident Involvement Rate (acc./100m veh-km)

DHV	300	500	1000	1500
Reduction in Accident Involvement Rate (Acc. per 100m veh-km)	125.88	187.72	167.85	194.35

The study of multiple measures of effectiveness requires the development of relative values. The measures are delay reduction (DR) and accident reduction (AR).

DHV	300	500	1000	1500
DR (hrs/yr)	533	1369	2739	5288
Relative Value for DR	0.10	0.26	0.52	1.00
AR (acc/yr)	1.7	4.4	7.7	13.4
Relative Value for AR	0.13	o.33	0.57	1.00

Example: Set the highest value of DR = 1 (on the scale of 0 to 1). Find the relative value of other DR estimates by taking ratios.
DR of 5288 = 1
DR of 5477 = (1/5288) x 2739 = 0.52
Weighting of effectiveness measures (user specified):

DR Delay reduction	Weight (w) =	0.4
AR Accident Reduction	Weight (w) =	0.6
		1.0

Weighted effectiveness:

DHV	Weighted Effectiveness
300	(W_{DR})(relative value for DR) + (W_{AR})(relative value for AR) = (0.4)(0.10) + (0.6)(0.13) = 0.12
500	(0.4)(0.26) + (0.6)(0.33) = 0.30
1000	(0.4)(0.52) + (0.6)(0.57) = 0.55
1500	(0.4)(1.00) + (0.6)(1.00) = 1.00

Economic feasibility study computations are described next. Benefit measures are DR and AR.

Base year = 1989
Real rate of return i = 5% for the case of "discounting of benefits".
i = 0% for the case of "no discounting of benefits".
Inflation f = 5%
N = 30 years
VT (in constant $ of 1989) = $5/h
VAC (in constant $ of 1989) = $5000 for property damage/accident* + $5000 (for injury, fatality)/accident*
= $10,000/accident

---

* In 1987, Ontario:
21,235 accidents were reported for "Other King's" Highways
402 fatalities were reported for these highways
14,735 persons were injured on these highways
$5000/accident (average) for property damage
1 fatality for 52.82 accidents
1 injury for 1.44 accidents.

Estimation of Benefits (Overtaking Allowed)

DHV	300	500	1000	1500
Without Discounting of Benefits				
Delay Reduction (hrs/yr)	533	1369	2739	5280
Benefits Due to Delay Reduction/Yr (1989$)	2665	6848	13695	26440
Reduction in Accidents/Yr	1.7	4.4	7.7	13.4
Benefits Due to Accident Reduction/Yr (1989$)	17000	44000	77000	134000
Benefits Due to Accident Reduction (Property Damage Only) (1989$)	8500	22000	38500	67000
With Discounting of Benefits				
Benefits Due to Delay Reduction/Yr 1989$)	1366	3509	7016	13549
Benefits Due to Accident Reduction/Yr (1989$)	8711	22546	39456	68664
Benefits Due to Accident Reduction (Property Damage Only) (1989$)	4356	11273	19728	34332

Cost of Climbing Lane/km (1989$) = $396,000/km

Maintenance Cost/km (1989$) = Assumed to be zero in this example

Total Cost/km = $396,000/km

Cost of Climbing Lane (1989$)/Yr = (2 km x $396,000)/30 yrs
= $26,400/yr

Net Benefits				
DHV	300	500	1000	1500
AADT	1724	2874	5747	8621
Without Discounting of Benefits				
Delay Reduction/ Yr (1989$)	2665	6848	13695	26440
Safety Benefits/ Yr (1989$)	17000	44000	77000	134000
Total Benefits/ Yr (1989$)	19665	50848	90695	160440
Cost/Yr (1989$)	26400	26400	26400	26400
Net Benefits/Yr (1989$)	-6735	24448	64295	134040
With Discounting of Benefits				
Delay Reduction/ Yr (1989$)	1366	3509	7016	13549
Safety Benefits/ Yr (1989$)	8711	22546	39456	68664
Total Benefits/Yr (1989$)	10077	26055	46472	82213
Cost/Yr (1989$)	26400	26400	26400	26400
Net Benefits/Yr (1989$)	-16323	-345	20072	55813

It can be noted from the above tabulated results that a climbing lane is feasible for a DHV of 500. The truck speed criterion is also positive. However, according to the level of service warrants/guidelines, a climbing lane would not be warranted at this level of traffic. The economic feasibility criterion has a more profound base than the LOS criterion for the provision of a climbing lane. Therefore, it would be logical to give a higher weight to the results of cost-effectiveness evaluation in decision-making.

Cost-Effectiveness				
DHV	300	500	1000	1500
AADT	1724	2874	5747	8621
Cost/ 100 Vehicles per Yr (1989$)	8.40	5.04	2.52	1.68
Cost/ 100 Veh-km (1989$)	1.91	1.15	0.57	0.38
Effectiveness: Single Measures				
Delay Reduction (hrs/yr)	533	1369	2739	5280
Delay Reduction (min/100 vehicles)	5.1	7.9	7.9	10.1
Veh-hrs of Delay Reduction/$ of Cost	0.02	0.05	0.11	0.20
$ of Cost/Veh-hr of Delay Reduction	49.53	19.28	9.63	5.00
Accident Reduction/Yr	1.7	4.4	7.7	13.4
Accident Reduction/ Million Veh-km	1.23	1.90	1.67	1.94
Accident Reduction/ $m of Cost	64.39	166.67	291.67	507.58
$ of Cost/Accident Reduction	15529	6000	3429	1970

Overall Effectiveness (Relative Value Scale)				
DHV	300	500	1000	1500
AADT	1724	2874	5747	8621
Index of Overall Effectiveness	0.12	0.30	0.55	1.00

Results of cost effectiveness evaluation clearly show that the cost-effectiveness of the climbing lane improves with increasing DHV.

Outputs of the PCL Program, covering effectiveness measures, economic feasibility, and cost-effectiveness type of evaluations are shown in Table 8.11.

It should be noted that the user has the option of specifying effective distance beyond the end of lane. In the present example, zero effective distance beyond the end of climbing lane was used. Microscopic simulations suggest that the effect of a climbing lane on the performance of the two lane highway is appreciable beyond the end of the lane. However, such an effect is not normally applicable beyond 3 kms from the end of the lane. The results of the present case can be regarded as extremely conservative. If an effective distance of 5200 m (i.e., 3000 m beyond the end of the lane) is used, there is no change in the level of service answer. On the other hand, the effectiveness estimates become more attractive. The default value for specifying the effective distance is 3 kms beyond the end of the lane.

A comparison of manual calculations and outputs of the PCL program suggests a general agreement. The differences are due to inconsistencies in the HCM (1985) figures applicable to some volume levels, rounding, and the number of significant digits used. In the refinement of the microcomputer program, the HCM (1985) figures were plotted and abrupt changes in functions were smoothed.

The PCL Program can be used to study sensitivity analyses. For example, the effect of grade on the satisfaction of warrants and the cost-effectiveness of the climbing lanes can be investigated. Reference 2 contains such illustrations.

Table 8.11

Economic Feasibility and Cost-Effectiveness Evaluation Outputs

PCL 2.05 - Effectiveness Measures

Mon Oct 28 22:12:58 1991

Site: example3 Example from final report

WEIGHTS
- Delay Reduction: 0.40
- Accident Reduction: 0.60

COST DATA
- Base Year: 1989
- Real Rate of Return: 5.00 %
- Facility Life: 30 yr
- Vehicle Hour Cost: 5.00 $
- Vehicle Acc. Cost: 10000 $
- Lane Unit Cost: 396000 $/km
- Maintenance Cost: 0 $/km/yr

SINGLE EFFECTIVENESS MEASURES: (Effective Distance = 2.20 km)

DHV	300	500	1000	1500	veh/hr
AADT	1724	2874	5747	8621	veh/day
Delay Red.	5.2	7.3	7.8	10.0	min/100 veh

Alt-H-Help. F1-Explain. Alt-F1-Keys. Ctrl-F1-About EffMeas F10-Options

Table 8.11 (Cont.)

Economic Feasibility and Cost-Effectiveness Evaluation Outputs

PCL 7.05 - Effectiveness Measures

Acc. Red.	1.30	1.77	1.68	1.94	acc/M veh-km

MULTIPLE EFFECTIVENESS MEASURES:

DHV	300	500	1000	1500	veh/hr
Delay Red.	0.105	0.244	0.519	1.000	relative
Acc. Red.	0.134	0.303	0.575	1.000	relative
Weighted Eff.	0.122	0.279	0.552	1.000	

COSTS OF ADDING CLIMBING LANE:

Lane Length = 2.00 km Roadway Length = 2.20 km
Lane Construction Cost = 396000 $/km
Lane Maintenance Cost = 0 $/km/yr

Total Lane Construction Cost =	792000 $ =	26400 $/yr
Total Lane Maintenance Cost	=	0 $/yr
TOTAL LANE COST	=	26400 $/yr

BENEFITS FROM ADDING CLIMBING LANE:

DHV	300	500	1000	1500	veh/hr

Alt-H-Help, F1-Explain, Alt-F1-Keys, Ctrl-F2-Menu, Esc-Esc, F10-Options

Table 8.11 (Continued)

Economic Feasibility and Cost-Effectiveness Evaluation Outputs

Delay Red.	549.6	1278.9	2718.1	5239.5	hr/yr
Acc. Red.	1.80	4.07	7.73	13.45	acc/yr
Without discounting of benefits:					
DR Benefits	2748	6394	13590	26198	1989$/yr
AR Benefits	17960	40730	77330	134530	1989$/yr
Total Benefits	20708	47124	90920	160728	1989$/yr
Net Benefits	-5692	20724	64520	134328	1989$/yr
With discounting of benefits using a 5.00% real rate of return:					
DR Benefits	1408	3277	6964	13424	1989$/yr
AR Benefits	9203	20871	39625	68935	1989$/yr
Total Benefits	10611	24147	46589	82359	1989$/yr
Net Benefits	-15789	-2253	20189	55959	1989$/yr
COST-EFFECTIVENESS VALUES:					
DHV	300	500	1000	1500	veh/hr
AADT	1724	2874	5747	8621	veh/day
Annual Cost	26400	26400	26400	26400	1989$/yr
Cost	4.20	2.52	1.26	0.84	1989$/100 veh
Cost	1.91	1.14	0.57	0.38	1989$/100 veh-km

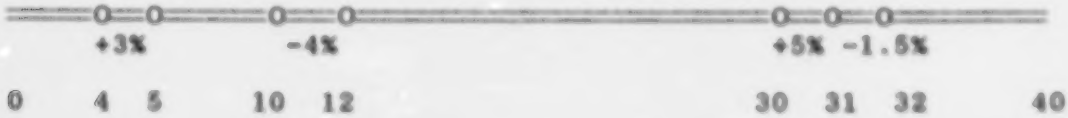
Alt-H-Help, F1-Explain, Alt-F1-Keys, Ctrl-F1-About Efficacy, F10-Options

COST-EFFECTIVENESS VALUES:					
DHV	300	500	1000	1500	veh/hr
AADT	1724	2874	5747	8621	veh/day
Annual Cost	26400	26400	26400	26400	1989$/yr
Cost	4.20	2.52	1.26	0.84	1989$/100 veh
Cost	1.91	1.14	0.57	0.38	1989$/100 veh-km
Effectiveness: Single Measures					
Delay Red.	550	1279	2718	5240	hr/yr
Delay Red.	5.24	7.32	7.77	9.99	min/100 veh
hr/$	0.02	0.05	0.10	0.20	veh-hr/1989$
$/hr	48.04	20.64	9.71	5.04	1989$/veh-hr
Acc. Red.	1.8	4.1	7.7	13.5	acc/yr
Acc. Red.	1.30	1.77	1.68	1.94	acc/M veh-km
acc red/$M	68.03	154.28	292.92	509.58	acc red/M1989$
$cost/acc red	14699	6482	3414	1962	1989$/acc red
Weighted Eff.	0.122	0.279	0.552	1.000	

8.5 Example Application 4: Analysis of Extended Sections of Two Lane Highways

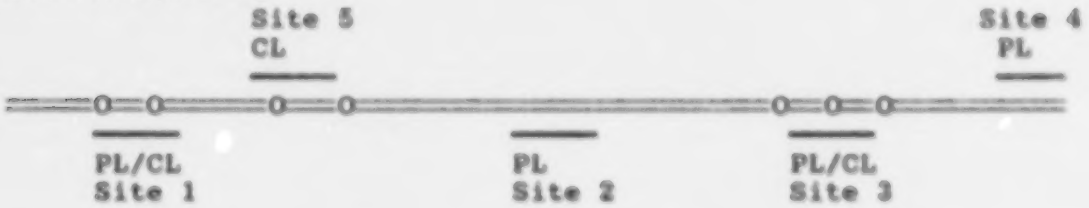
A two lane rural highway in level terrain is carrying 800 vehicles/hour. Design speed is 100 km/h. Traffic is forecast to grow to 1000 veh/h in 10 years and 1500 veh/h in 15 years. The directional split is 50% for each direction of flow. Percent trucks amount to 15% and RVs are 10%. The highway section under study has 30% no passing zones. The following features of the highway are also known. It is intended to investigate the feasibility of providing passing/climbing lanes at appropriate sites and to establish priorities for investment programming purposes.

Site Characteristics:



With the exception of grades shown, other parts of the site can be considered as level terrain.

Auxiliary Lanes:



Note: CL Climbing lane
PL Passing lane

The following input information has been used for the analysis of climbing and passing lane options. All other variables take default values.

- Base year 1991
- Vehicle hour cost $7.00
- Accident cost $15,000/accident
- Lane construction cost $450,000/km
- Maintenance cost $1,000/km/yr
- Heavy truck 180 kg/kw

Site 1: Climbing Lane Option

0 km 4.388 km 5.888 km 10.0 km

The starting point for the section analyzed is at km 4, the base of section with +3% grade and the end point is at 3 kms beyond the end of the climbing lane. Highlights of results are given below:

- Computerized method of establishing truck climbing lane length, starting and ending points
- Truck climbing lane of 1500 m; starting and ending points are shown above.
- Truck climbing lane warrants are met
- Level of service (LOS) warrant is not met for DHVs of 800, 1000 & 1200; for DHV of 1500, LOS warrant is met.
- Net benefits (with discounting) 1991$/year:

DHV 800	-7,151
DHV 1000	3,157
DHV 1200	16,757
DHV 1500	42,898

- At DHV of 800 vehicles/hour:

$ cost/accident reduced (1991 $)	12,592
Weighted effectiveness (relative values, 1 being maximum)	0.244

- Comment: A grade of 3% is low for meeting climbing lane LOS warrants or for meeting economic feasibility requirements even at 800 veh/h. This site should be analyzed as a passing lane with an effective distance of 6 km, extending to the next auxiliary lane proposed for the opposing direction.

Site 1: Passing Lane Option

Highlights of results are shown below.

0 km 4 km 6 km 10 km

. Assured passing opportunity criteria are not met by highway without passing lane. Therefore a passing lane should be considered for this site. Assume high platooning conditions for this example.

. Level of service (based on % time delay)

DHV	Without passing lane	With passing lane
800	C	C
1000	D	C
1200	D	D
1500	E	D

. The level of service falls below B. Therefore an auxiliary lane would of assistance, although such a lane does not appear to bring the level of service to B level.

. It should be noted that the level of service and speed comparisons cannot be made between passing lane analysis results and climbing lane analysis results. The climbing lane level of service analysis is based on highway capacity manual (1985) procedures applicable to specific grades. The level of service criteria used for level and rolling terrain analysis in the context of passing lane decisions are different from specific grade level of service criteria. As noted in our MTO sponsored report on the cost-effectiveness of climbing lanes, the 1985 HCM procedures for level/rolling terrain analysis have not been made compatible with those for specific grades [2,5,35].

. Net benefits (with discounting) 1991$/year

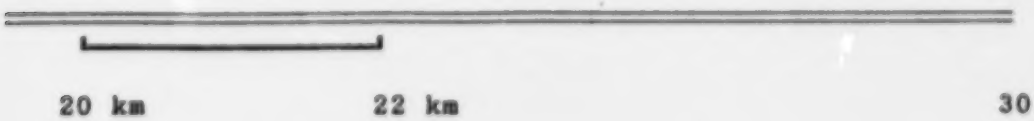
DHV 800	16,216
DHV 1000	28,715
DHV 1200	41,439
DHV 1500	60,992

. The passing lane is economically feasible for all DHV levels analyzed.

. At DHV of 800 vehicles/hour:
cost per accident reduction amounts to $6,524 (1991 $)
weighted effectiveness:
(relative values, 1 being the maximum): 0.507

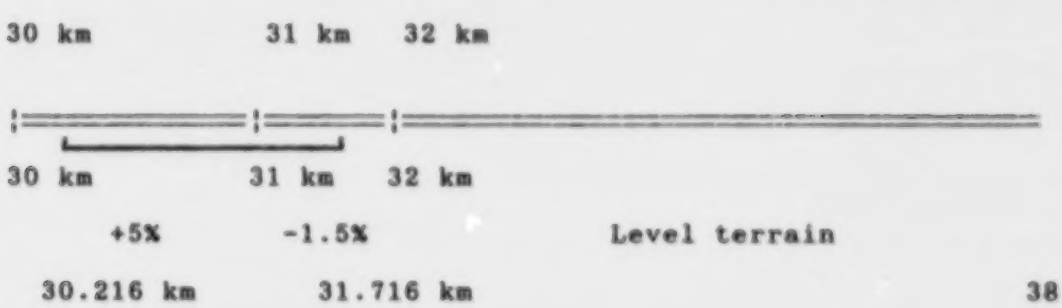
. Conclusion: Provide a passing lane of 2,000 m at site 1.

Site 2: Passing Lane



Results of the PCL program suggest that a passing lane is feasible at this location.

Site 3: Climbing Lane/Passing Lane:



Highlights of results:

. Truck climbing lane criteria are met
. A 1500 m lane should start at 30.216 km and end at 31.716 km.
. The LOS warrants are met at 1200 DHV and higher volumes.
. Net benefits are positive for 800 veh/h and higher volumes.
. If the auxiliary lane of 2km length is analyzed as a passing lane with an effective distance of 8 km, it becomes feasible.
. Provide a passing lane/climbing lane of 2,000 m at this site.

Site 4: Passing Lane

A passing lane of 2 kms with an effective distance of 8 kms is feasible at this site.

Site 5: Climbing Lane

Highlights of results are given below:

- A climbing lane of 2,820 m length starting at 11.723 km and ending at 8.903 km is feasible on the basis of all criteria, namely truck climbing warrants, level of service warrants, economic feasibility (even with discounting of benefits).

Establishment of Priorities

On the basis of net benefits, cost-effectiveness and climbing lane warrants, the following ranking of sites has been arrived at:

Rank	Site	Improvement
1	Site 5	Climbing lane, 2820 m
2	Site 3	Passing/Climbing lane, 2000 m
3	Site 1	Passing/climbing lane, 2000 m
4	Sites 2 & 4	Passing lanes, 2000 m each

Chapter 9

CONCLUSIONS AND RECOMMENDATIONS

9.1 Conclusions

The following conclusions can be drawn from the research conducted and the findings reported here.

1. This study has resulted in a methodology for level of service analysis of two lane highway sections with passing lanes. In a previous study funded by the MTO, a methodology was reported for the analysis of level of service of two lane highway sections with climbing lanes. The Highway Capacity Manual (1985) and other design manuals currently in use do not offer guidelines or methodology for this purpose. The microscopic simulation programs (e.g., TWOPAS, TRRAR) can be used for estimating platooning, average speed, and other operational performance measures. However, these programs are not readily available to designers and may not be viewed as "practical" for the assessment of auxiliary lane options.

2. The methodology developed in this study enables the estimation of measures required to check conventional warrants for climbing lanes. Additionally, this research has incorporated in the methodological framework, techniques for conducting economic feasibility and cost-effectiveness studies.

3. The methodology developed enables the analysis of passing lanes as well as climbing lanes for a given site or over extended sections of a two lane highway. The methodology can be used to develop priorities for site improvements involving passing lanes as well as climbing lanes.

4. The development of methodology for assessing the operational performance of two lane highway sections with and without passing lane involved the study of traffic platooning measures (i.e., percent of vehicles in platoons or percent time delay) and traffic speed measures. Both measures are used to establish level of service. It should be recognized that percent time delay is recommended by the HCM (1985) as an indicator of level of service. However, due to the difficulties in quantifying this measure in dollar terms, change in average speed (ie., delay) is used in the economic feasibility methodology.

5. The two microsimulation models, namely the TWOPAS and TRARR have generally similar capabilities. A comparison of their results suggests that these are comparable. For this study, the TWOPAS simulator was selected on the basis of its outputs and experience with applications.

6. The approach adopted in this study for the development of models that are used to estimate platooning and average speed of two lane highways with and without passing lanes, has proven to be appropriate and efficient for the task at hand. The use of the outputs of the microscopic simulation of highway sections in conjunction with geometric and traffic features for the calibration of regression models of platooning and average speed is an affordable, reliable and effective approach. The regression equations provide answers that are as realistic as those obtained from the microscopic simulation model. The regression equations can therefore be used for providing realistic estimates of the performance of highway section with and without passing lanes.

7. A comparison of field survey data collected from sites with and without passing lanes checks favourably with results obtained from the use of equations. It should be stressed that he microscopic simulation models (i.e., TWOPAS, TRRAR) are useful for a very detailed microsimulation of two lane highways. However, the regression models have been found to be very satisfactory for macrosimulation of such sites.

8. The level of service criteria (LOS) given in the HCM (1985) are not consistent for the analysis of level/rolling sections as opposed to upgrade sections. The user of the CECL program or the climbing lane analysis program contained in the PCL package should be aware of this limitation of LOS criteria attributed to the HCM (1985).

9. The regression models are able to incorporate the essential characteristics of two highway sections including traffic. Their use provides a realistic basis for the operational analysis of two lane highway sections with and without auxiliary lanes. Prior to this research, a methodology of such scope was not available.

10. Safety information examined suggests that accident involvement rates rise directly in response to increased traffic and the resulting drop in average speed. Auxiliary lanes are effective in reducing accidents within the widened roadway section as well as downstream due to increased opportunities to pass slow vehicles, reduction in platoons and improved operating speeds.

11. The determinants of the effectiveness of a passing lane are: length of lane, degree of overtaking allowed over an extended section of a two lane highway, length of highway section, traffic volume, percent trucks, percent recreational vehicles, directional distribution of traffic, and terrain. Clearly, all the roadway and traffic features that contribute to the formation of platoons and decrease in operating speed are incorporated in the regression equations.

12. Highlights of results of operational performance tests suggest the following observations.

    . Percent of vehicles in platoons is a more sensitive measure of level of service than spot or average speed.

    . Platooning is very sensitive to changes in traffic volume; volume is the most important variable in explaining % of vehicles in platoons and average speed.

    . Percent trucks and % RVs have a higher effect on platooning and average speed on grade as compared to level and rolling terrain.

    . In a number of cases, trucks have a higher effect on platooning than RVs for a two lane road without a passing lane. On the other hand, on level and moderately rolling terrain, RVs appear to have a higher effect than trucks on speed and platooning for road sections with a passing lane.

    . Highway design and control features in the form of restrictions on overtaking affect the performance of two lane highways.

    . The % no-passing zones has an appreciable effect on % of vehicles in platoons.

    . The % of vehicles in platoons is about the same for level and rolling terrain.

    . Average speed is lower for rolling vs. level terrain.

12. Passing lanes improve traffic flow in terms of reducing platooning and improving speed for a considerable distance downstream from the start of such lanes. However, the effect of passing lanes becomes negligible beyond 13 to 16 kms from the start of such lanes.

13. Longer passing lanes have a somewhat higher effect on the reduction of platooning than shorter lanes. However, when viewed in terms of net benefits, a 1 to 2 km lane is more effective than a 3 km lane.

14. The best length of lane increases somewhat with volume and the effective length decreases with volume:

Traffic	Passing Lane Length	Effective Distance
500-750 DHV	1.0 to 1.6 km	13.0 km
800-1000 DHV	2.0 km	10.0 km
Over 1000 DHV	2.0 km	8.0 km

15. The cost-effectiveness methodology is useful for assessing passing lane/climbing lane alternatives and for testing the economic viability of passing lane options. The same site could be analyzed for passing and climbing lane installations. Also, priorities can be established through the use of this method.

16. On the basis of sensitivity tests and example applications, passing lanes, despite their substantial capital cost, appear to be cost-effective and economically feasible, for higher traffic volume levels. Volume warrants are difficult to establish, given the diversity of road geometric conditions that could change economic feasibility answers. However, in general, passing lanes become feasible for DHVs higher than 500.

17. For low grades (e.g., 3%) in association with a shorter length of grade, a site may not appear to be feasible for a climbing lane installation for DHVs as high as 750. Such sites show higher effectiveness and net benefits when analyzed as passing lanes.

18. The microcomputer program, PCL, incorporating the overall methodology for passing as well as climbing lane analysis, is an effective, user friendly tool. It enables:

    . an expedient and comprehensive assessment of passing and climbing lane projects,

    . analysis of given site as passing or a climbing lane, and

    . priorities to be established between sites competing for investment dollars.

9.2 Recommendations

1. The methodology for checking criteria for the provision of a passing lane, for operational and safety analysis, for economic feasibility and cost-effectiveness evaluations, and for comparative assessment of passing and climbing lanes for same or different sites should be adopted by the Ministry of Transportation, Ontario.

2. Accident prediction models should be researched further by using Ontario data. Such models should be of the form used in this study, showing accident reduction as function of improvement in average speed.

3. Measures of operational performance of two lane highways, with and without auxiliary lanes should investigated (e.g., percent passing opportunity).

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APPENDIX A

SENSITIVITY TEST RESULTS

This appendix contains selected sensitivity analysis results. Changes in platooning and average speed are illustrated in Figure A.1 to A.24.

In all cases, the road length used is 8 km and a passing lane of 2 km is assumed. Factors that were varied are:

- traffic volume
- % trucks
- % RVs
- Terrain
- Percent "no passing zones"

A explanation of abbreviations used in Figures A.1 to A.24 is provided below.

R	Road length
PL	Passing lane
T	Truck
RV	Recreational vehicle
VPH	Vehicles per hour

FIG.A.1: % IN PLATOONS (ADV. DIRECTION)

LEVEL,PASSING ALLOWED,R=8KM,PL=2KM

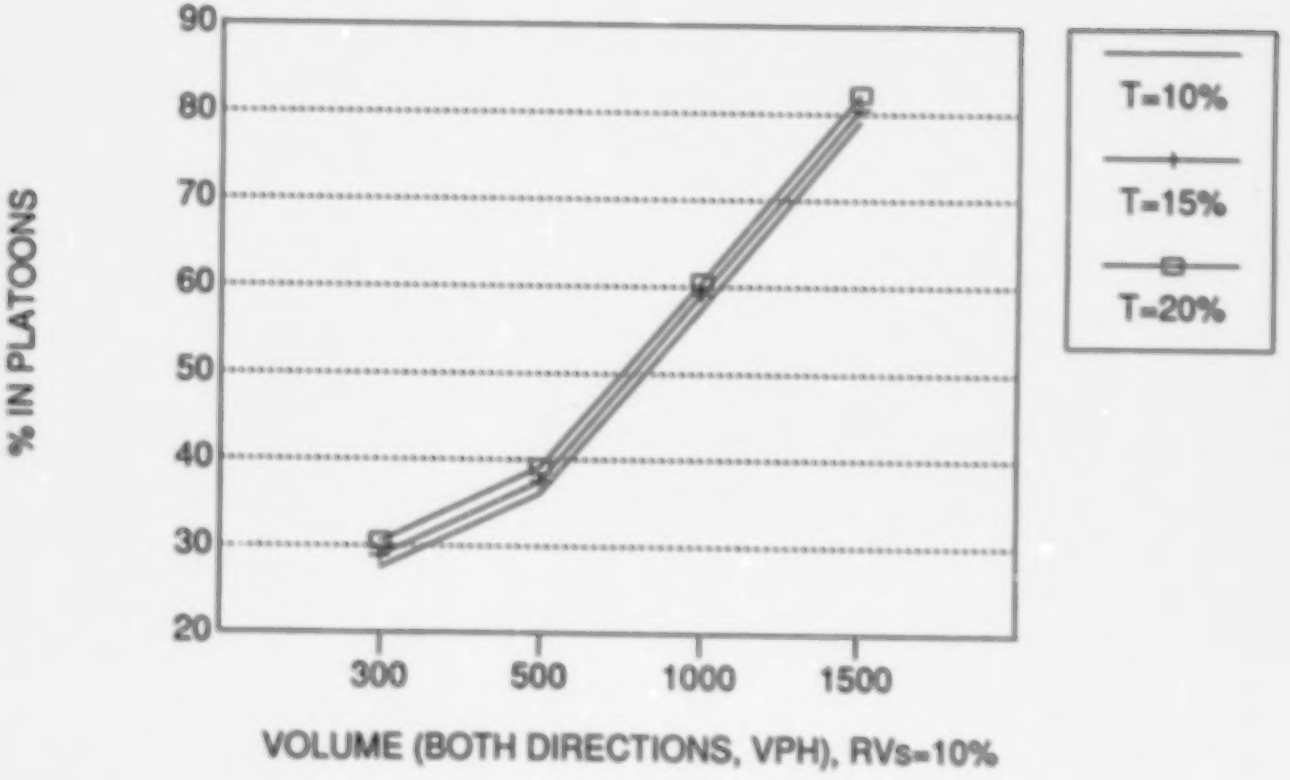


FIG.A.2: % IN PLATOONS (ADV. DIRECTION)

LEVEL,50% PASSING ZONE,R=8KM,PL=2KM

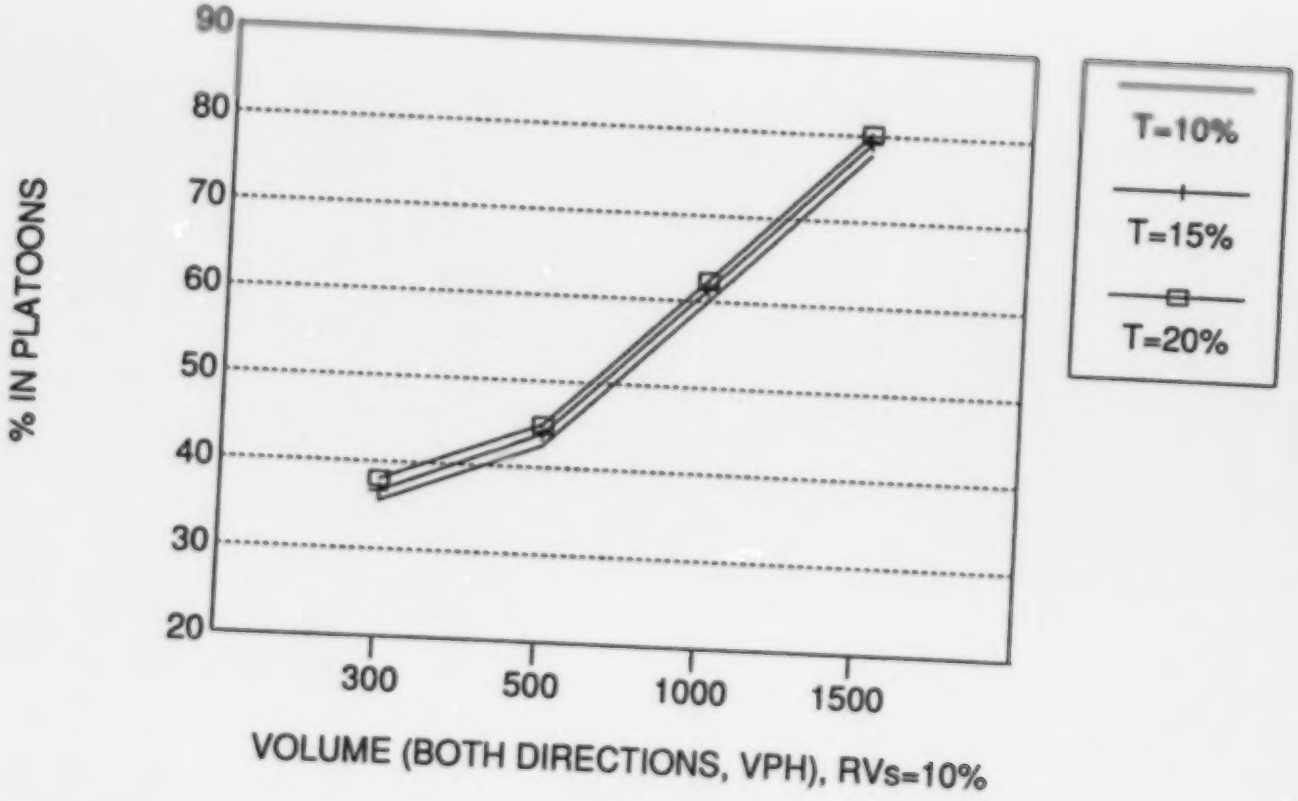


FIG.A.3: % IN PLATOONS (ADV. DIRECTION)

LEVEL,PASSING ALLOWED,R=8KM,PL=2KM

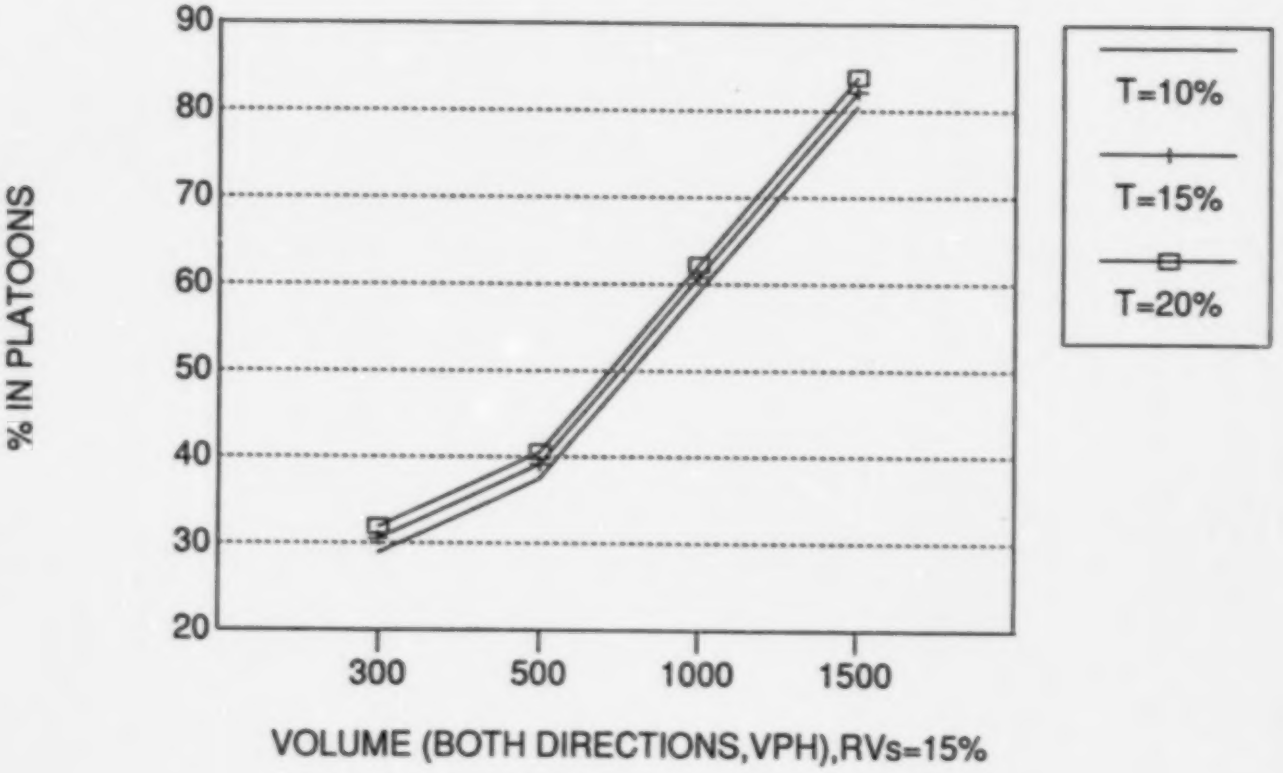


FIG.A.4: % IN PLATOONS (ADV. DIRECTION)

LEVEL,50% PASSING ZONE,R=8KM,PL=2KM

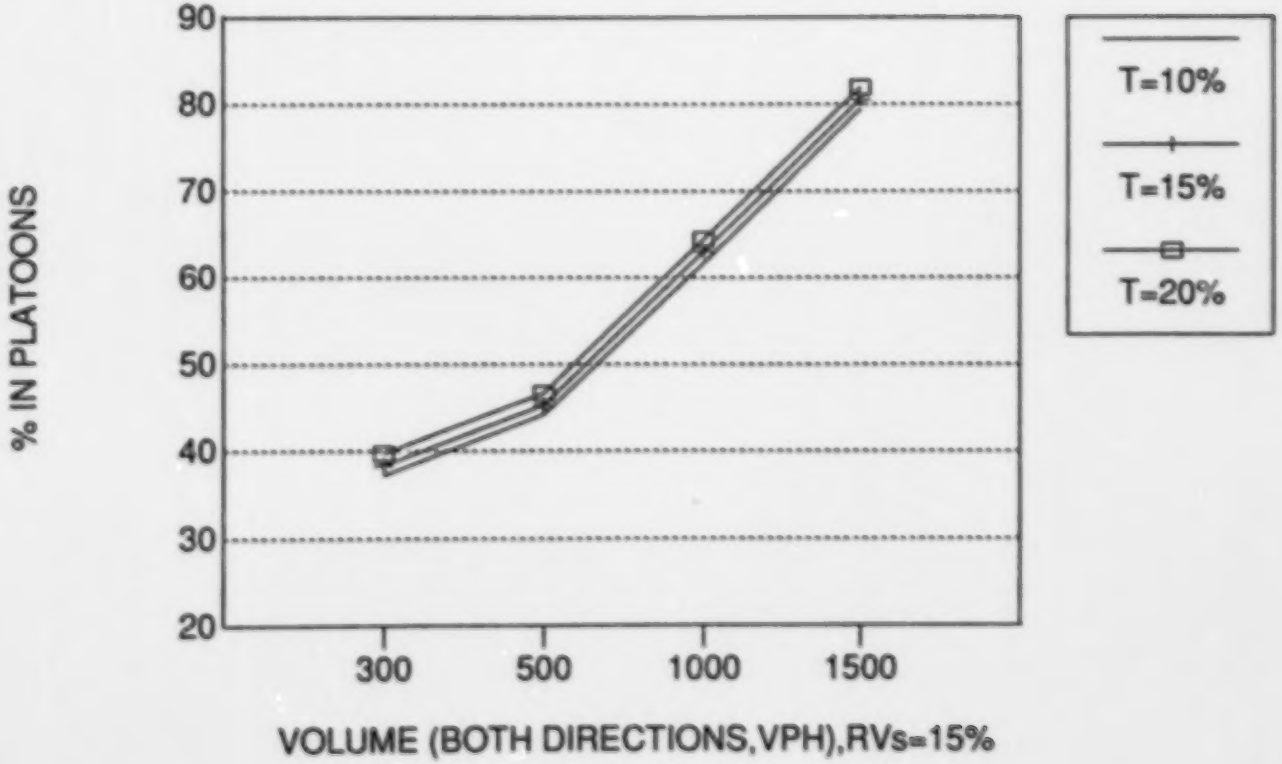


FIG.A.5: % IN PLATOONS (ADV. DIRECTION)

LEVEL,PASSING ALLOWED,R=8KM,PL=2KM

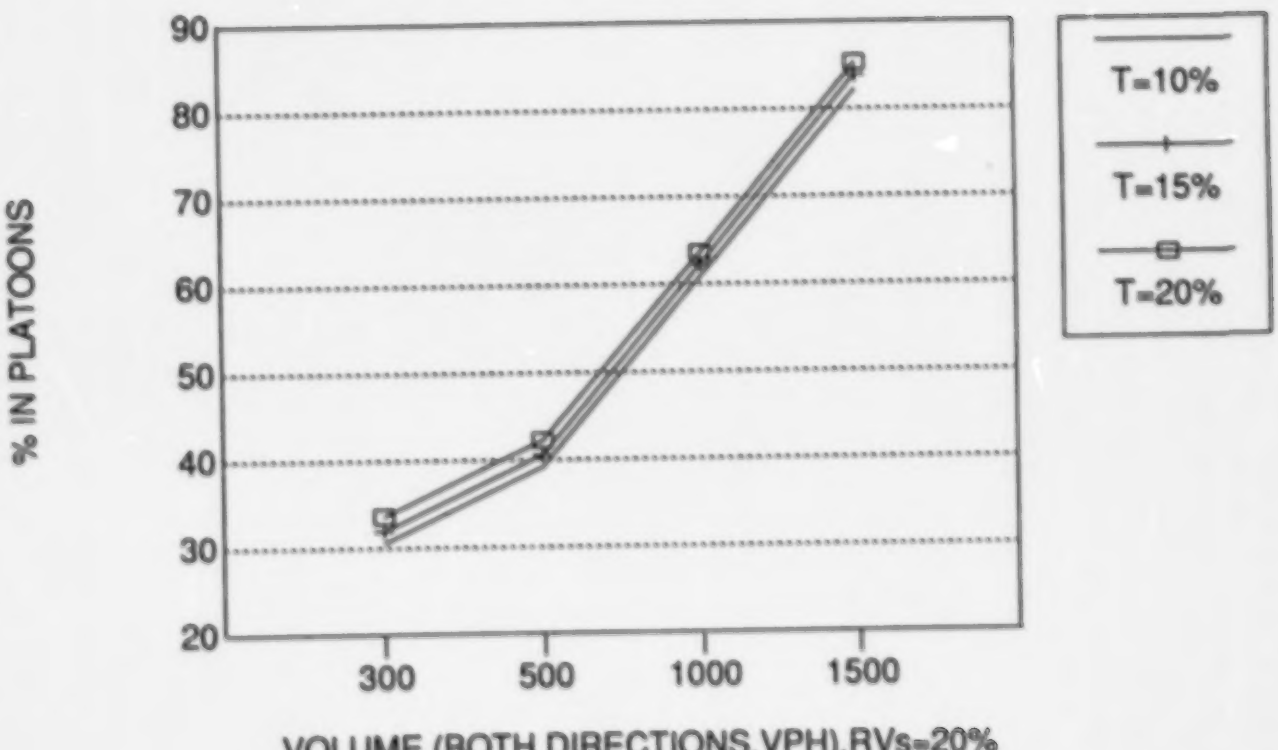


FIG.A.6: % IN PLATOONS (ADV. DIRECTION)

LEVEL,50% PASSING ZONE,R=8KM,PL=2KM

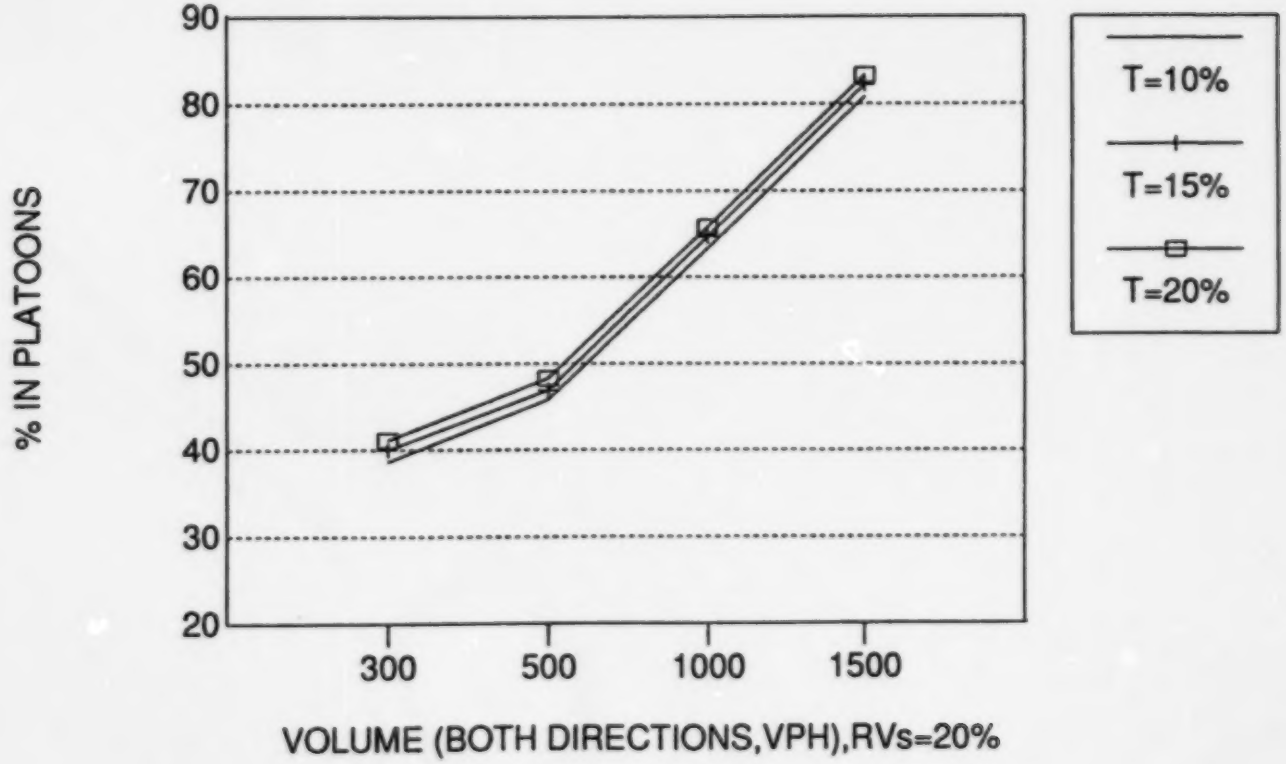


FIG.A.7: % IN PLATOONS (ADV. DIRECTION)

LEVEL,50% PASSING ZONE,R=8KM,PL=2KM

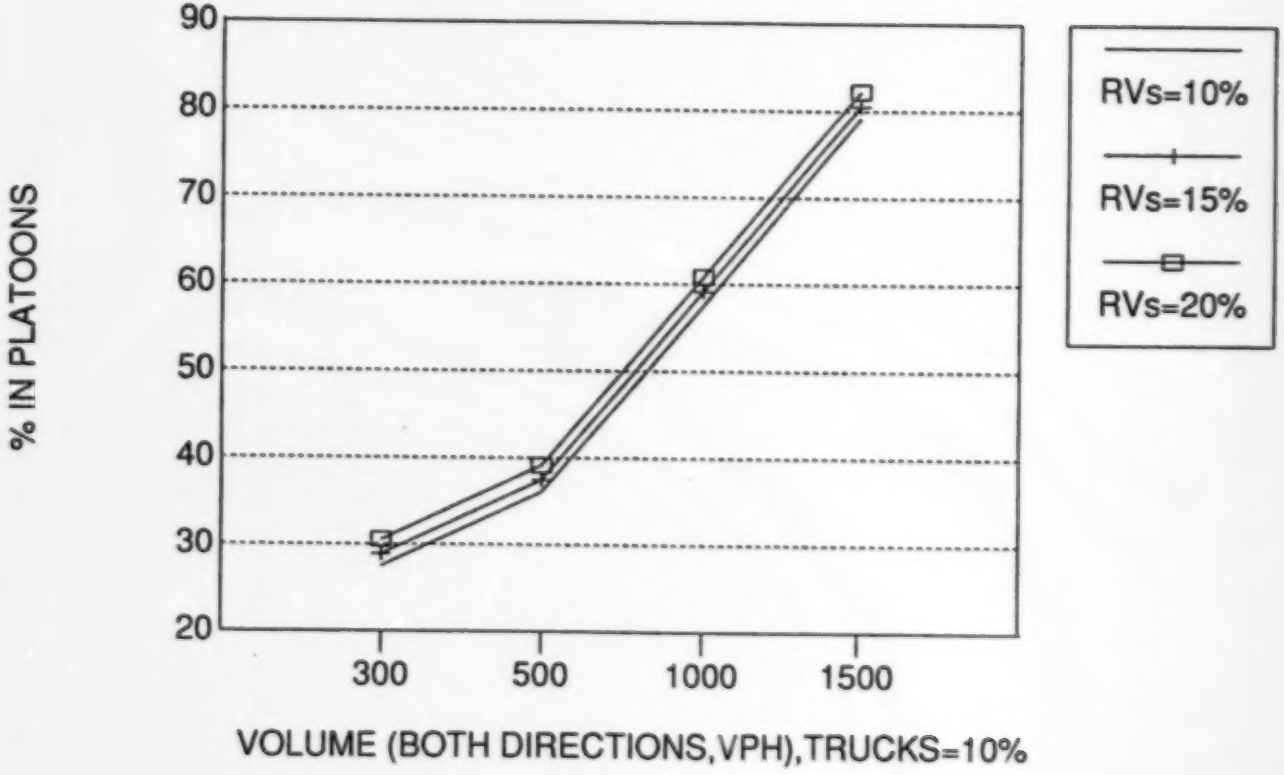


FIG.A.8: % IN PLATOONS (ADV. DIRECTION)

LEVEL,50% PASSING ZONE,R=8KM,PL=2KM

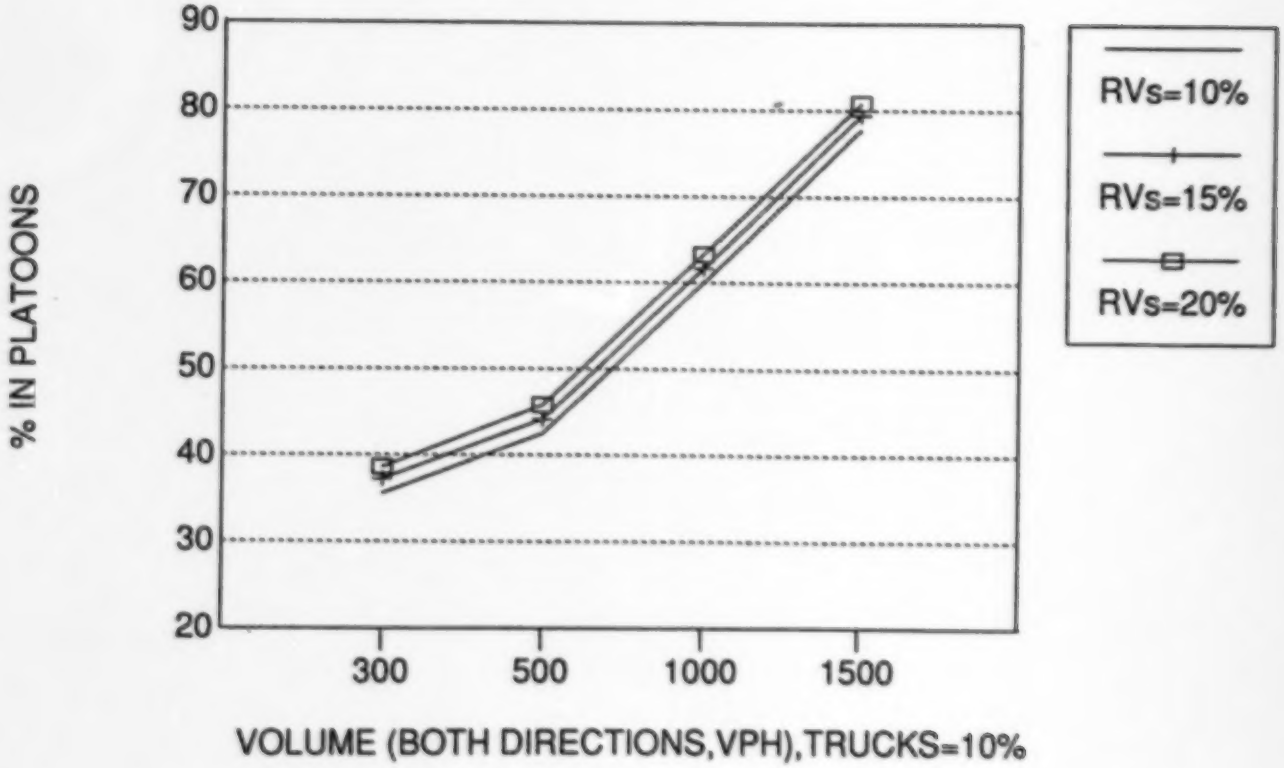


FIG.A.9: % IN PLATOONS (ADV. DIRECTION)

ROLLING,PASSING ALLOWED,R=8KM,PL=2KM

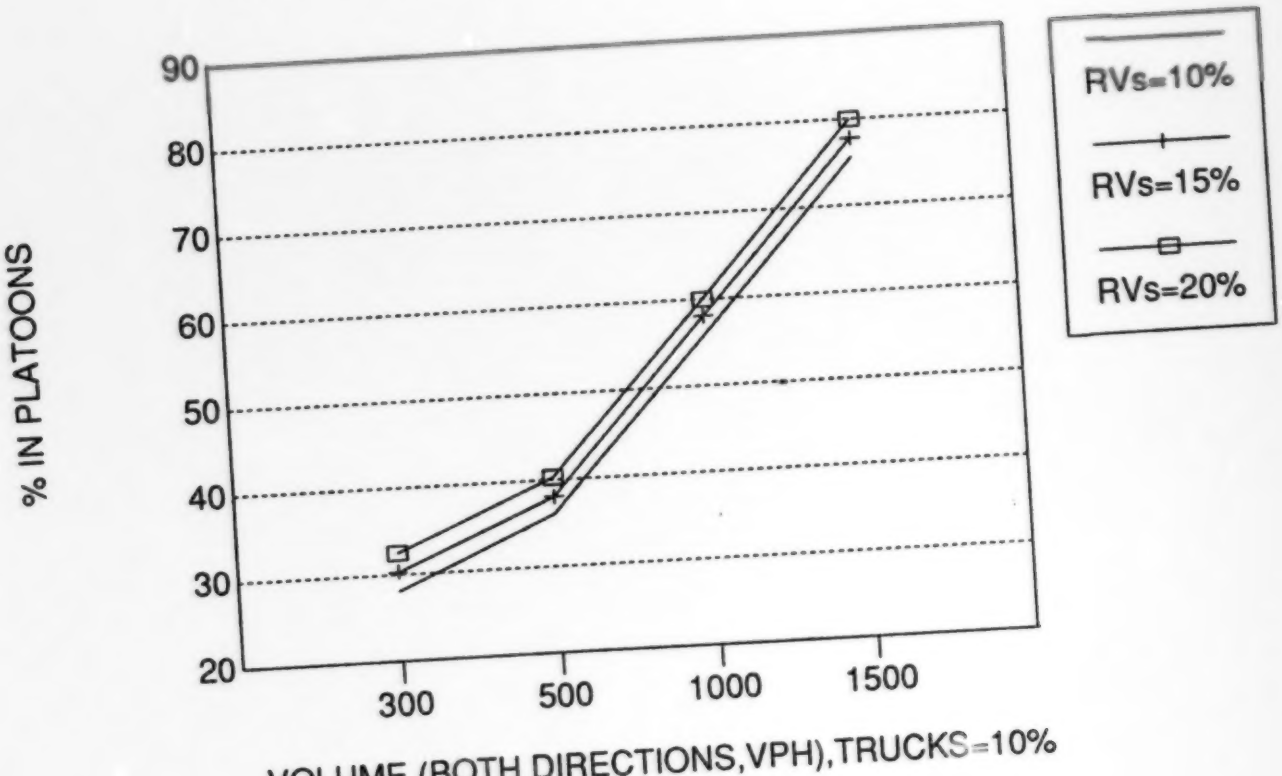


FIG.A.10:% IN PLATOONS (ADV. DIRECTION)

ROLLING,50% PASSING ZONE,R=8KM,PL=2KM

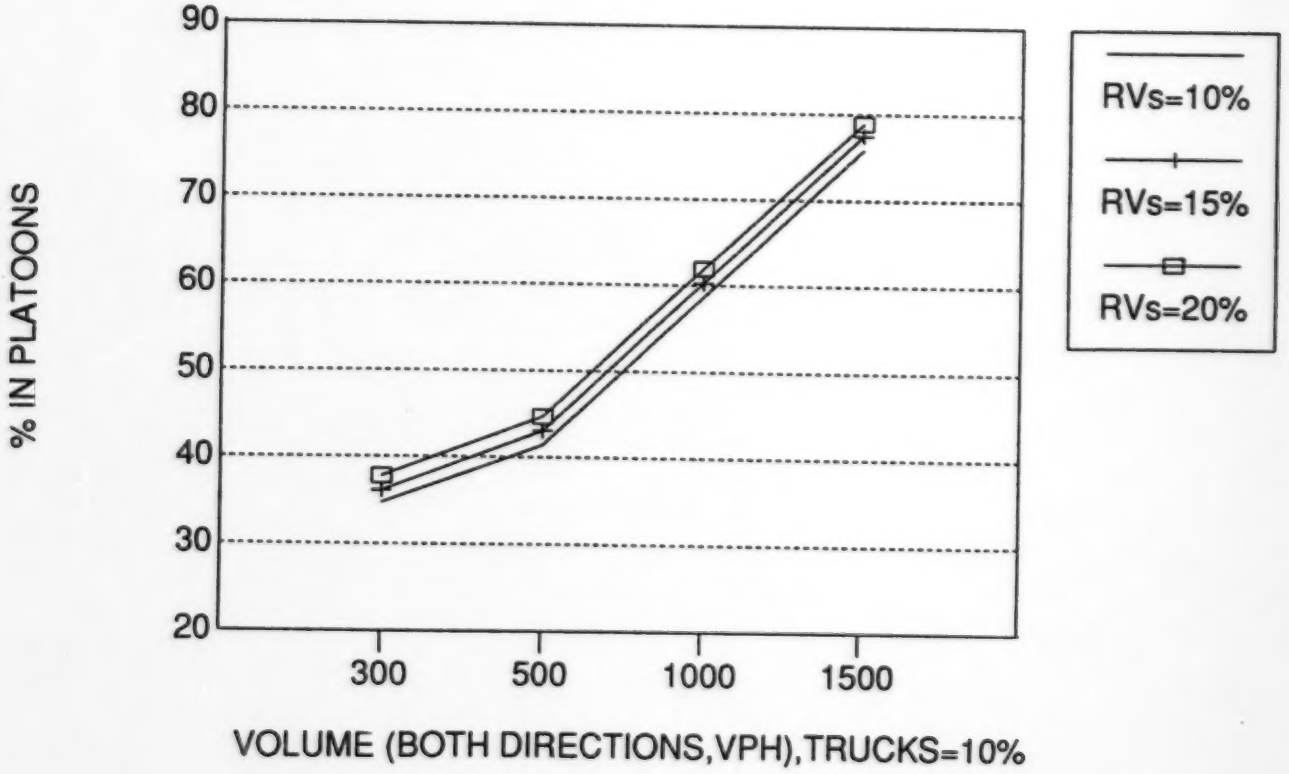


FIG.A.11:% IN PLATOONS (ADV. DIRECTION)

LEVEL,PASSING ALLOWED,R=8KM,PL=2KM

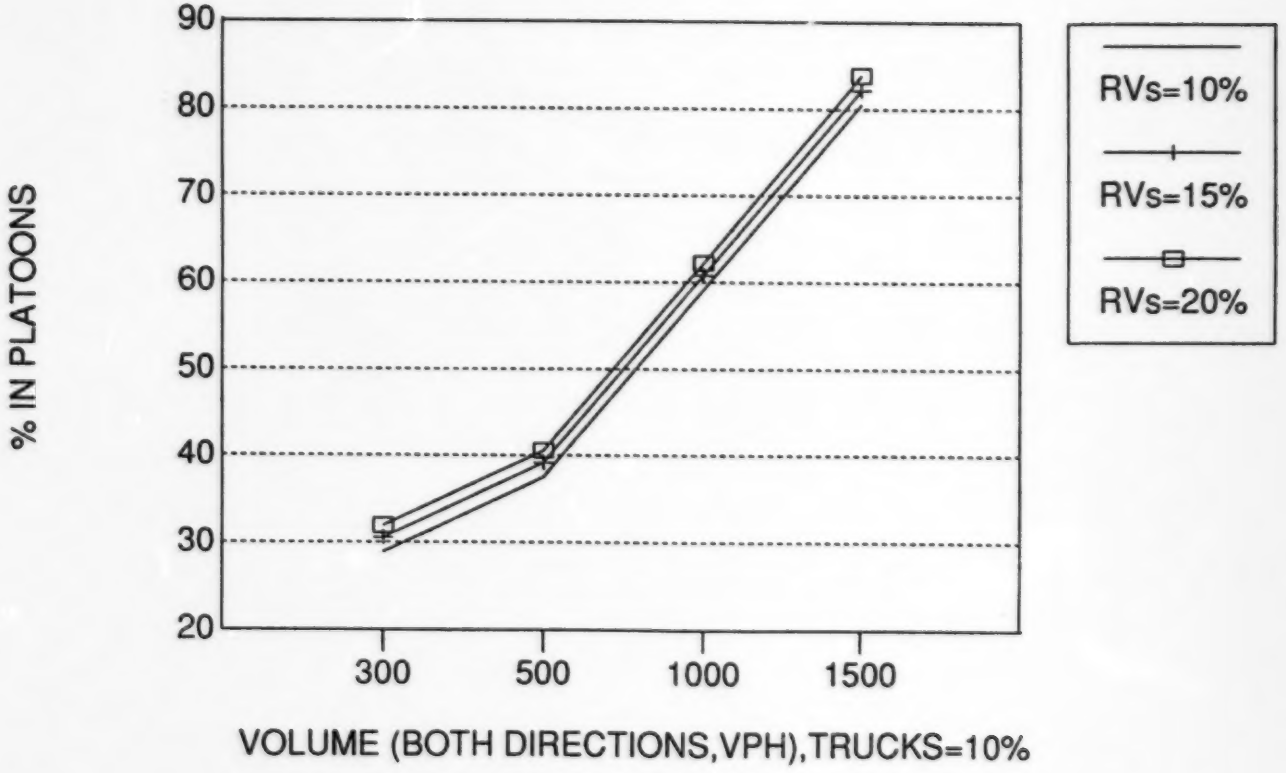


FIG.A.12:% IN PLATOONS (ADV. DIRECTION)

ROLLING,50% PASSING ZONE,R=8KM,PL=2KM

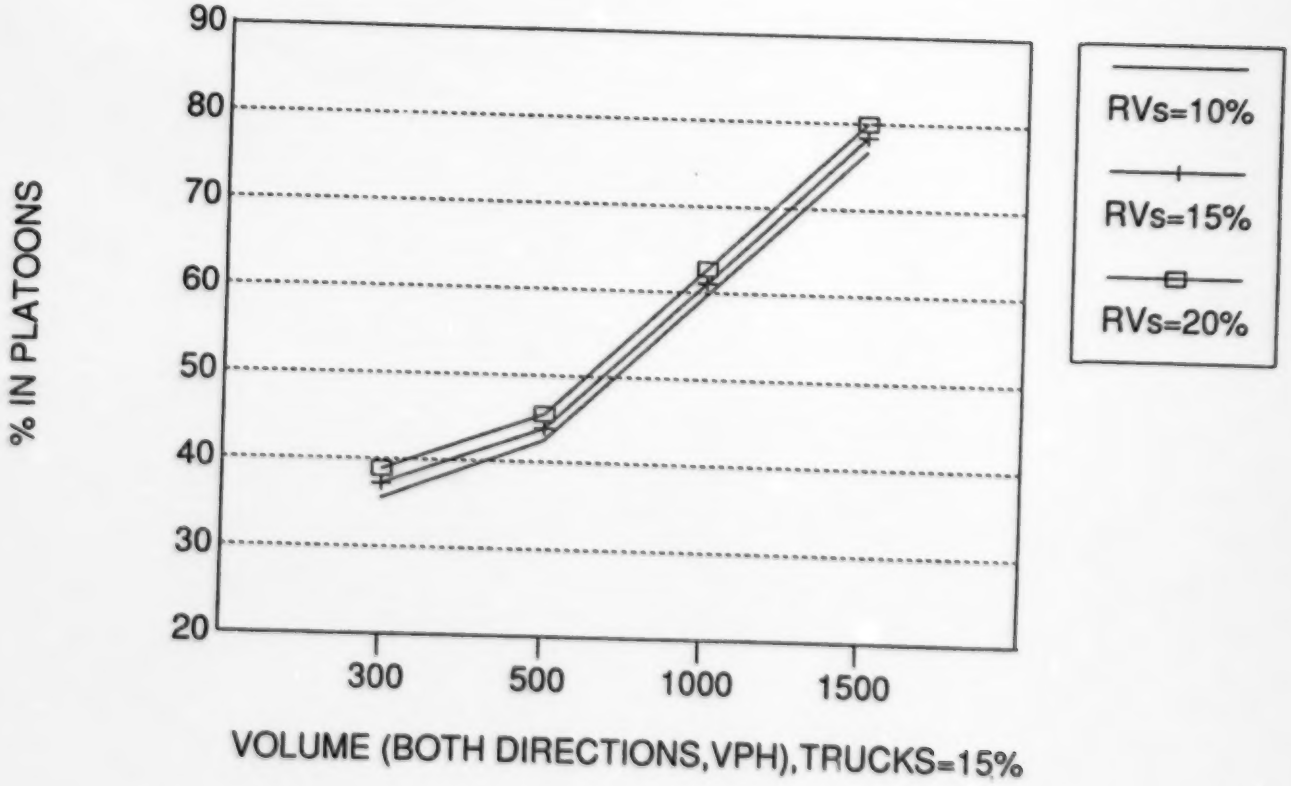


FIG.A.13:% IN PLATOONS (ADV. DIRECTION)

ROLLING,PASSING ALLOWED,R=8KM,PL=2K

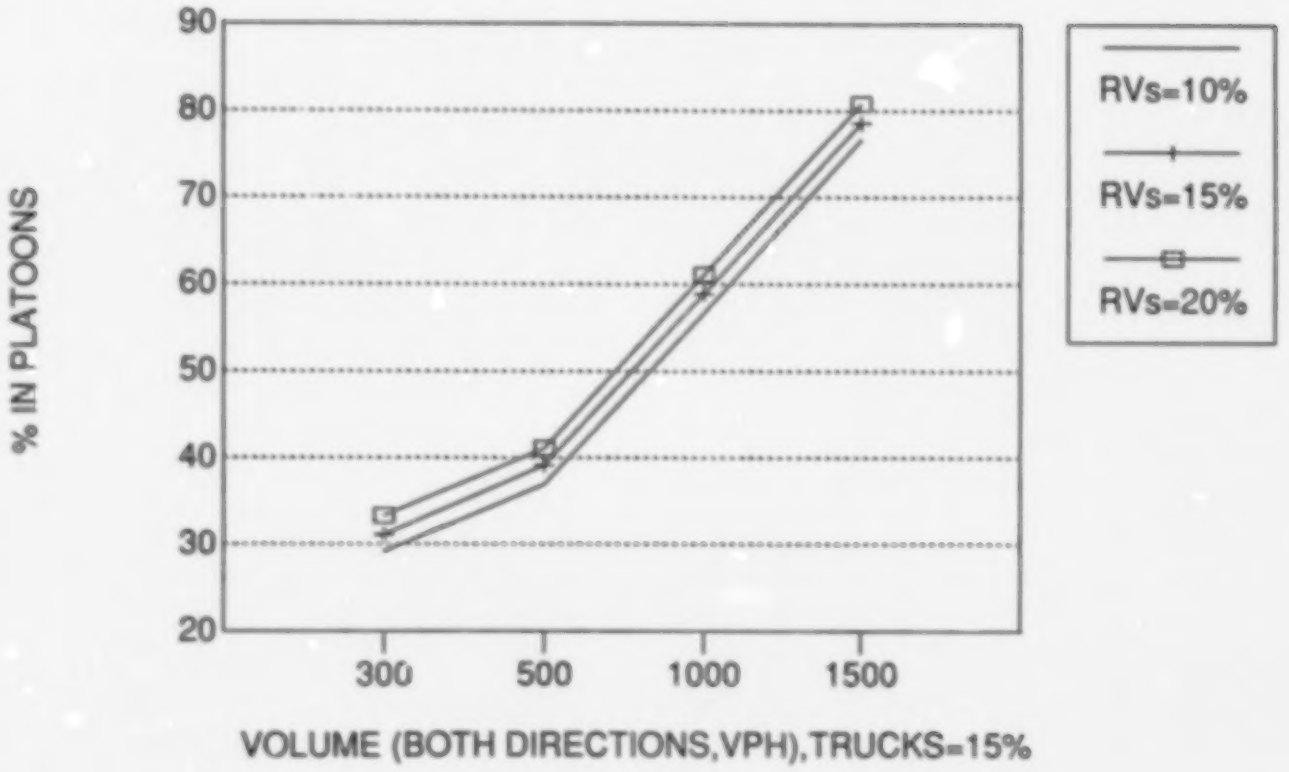


FIG.A.14:% IN PLATOONS (ADV. DIRECTION)

ROLLING,50% PASSING ZONE,R=8KM,PL=2K

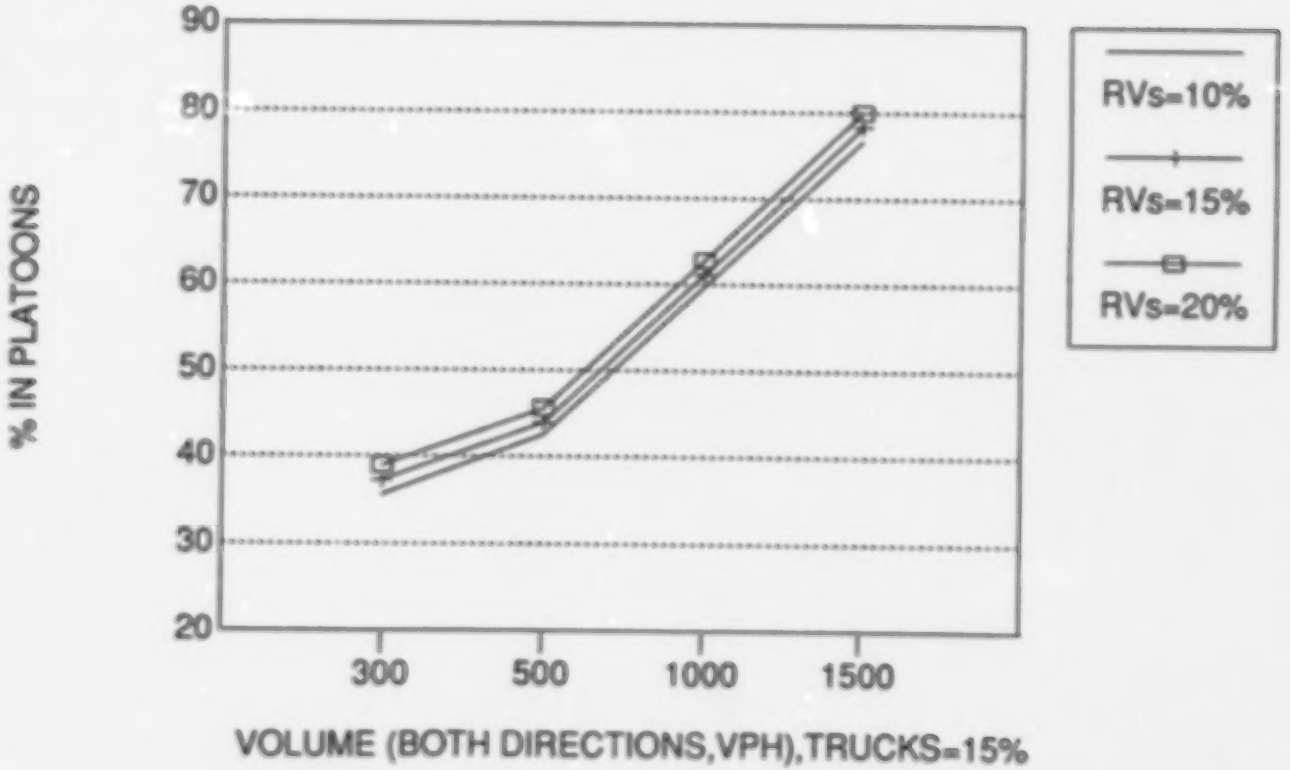


FIG.A.15: AVG. SPEED (BOTH DIRECTIONS)

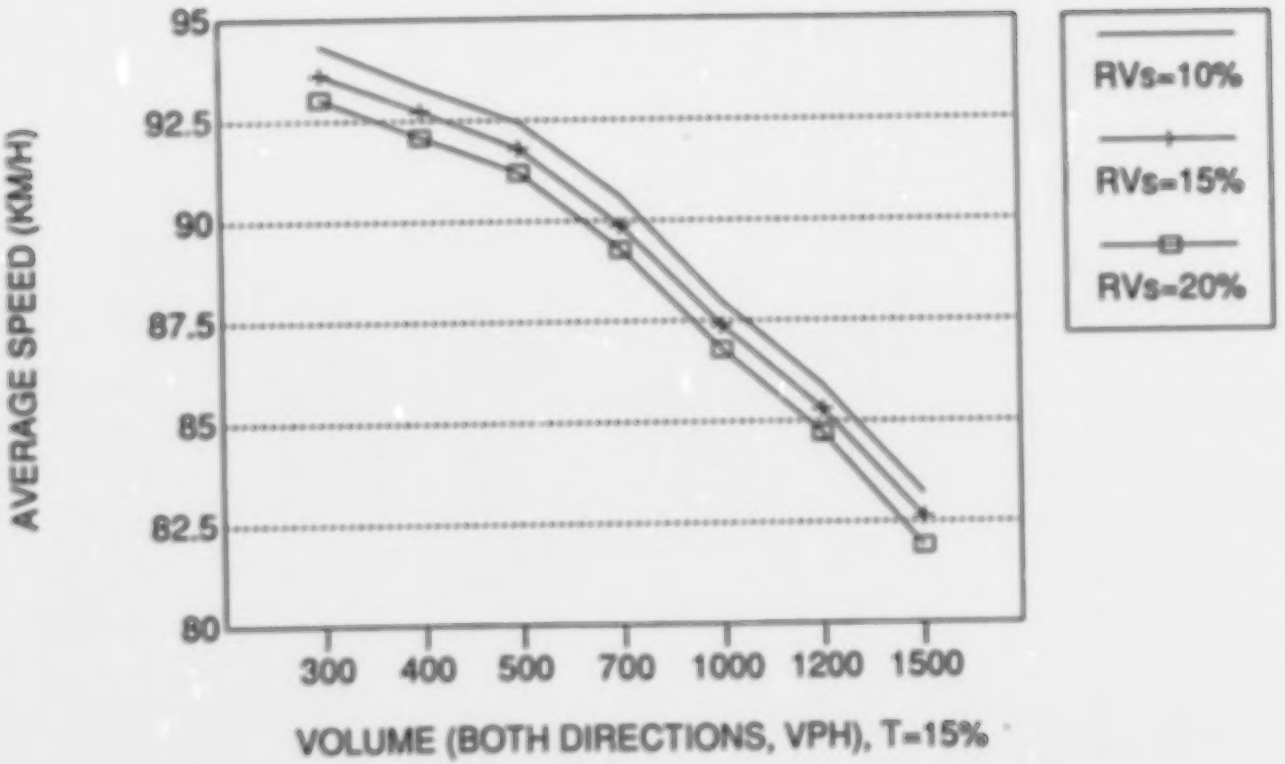


FIG.A.16: AVG. SPEED (BOTH DIRECTIONS)

LEVEL,PASSING ALLOWED,R=8KM,PL=2KM

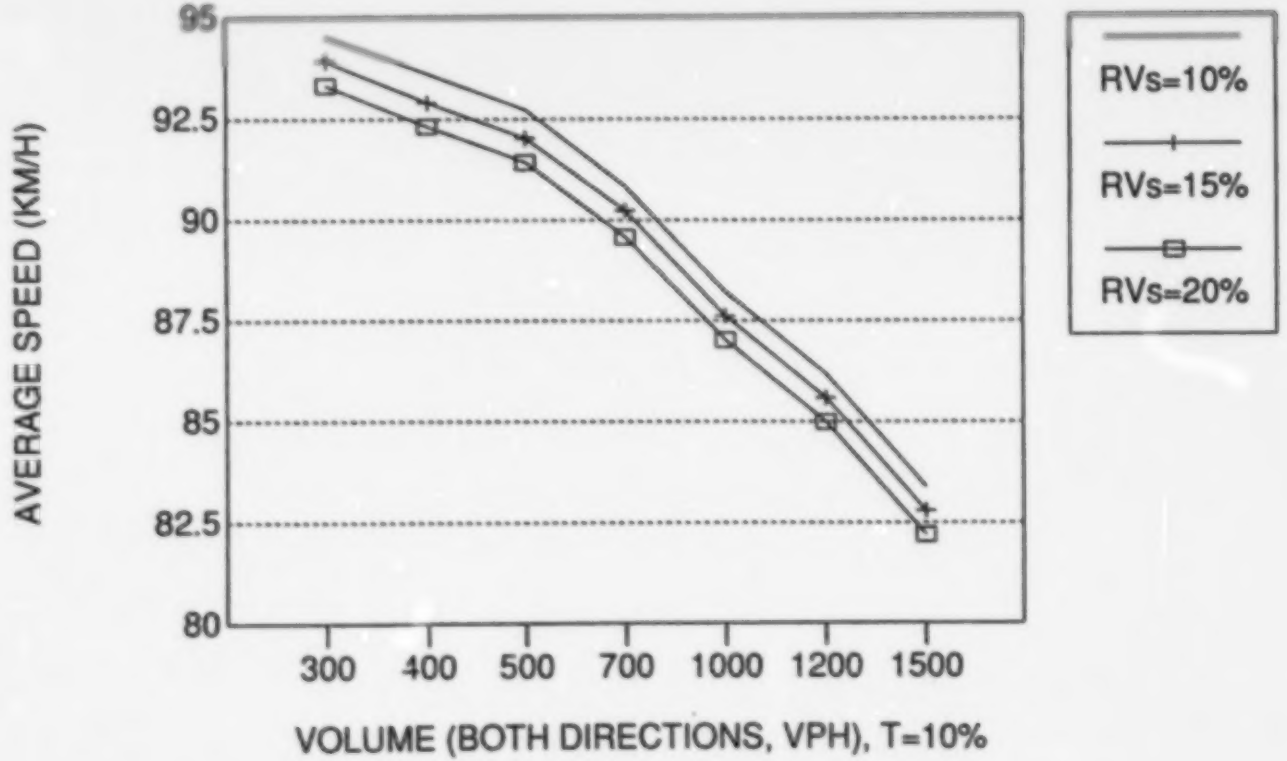


FIG.A.17: AVG. SPEED (BOTH DIRECTIONS)

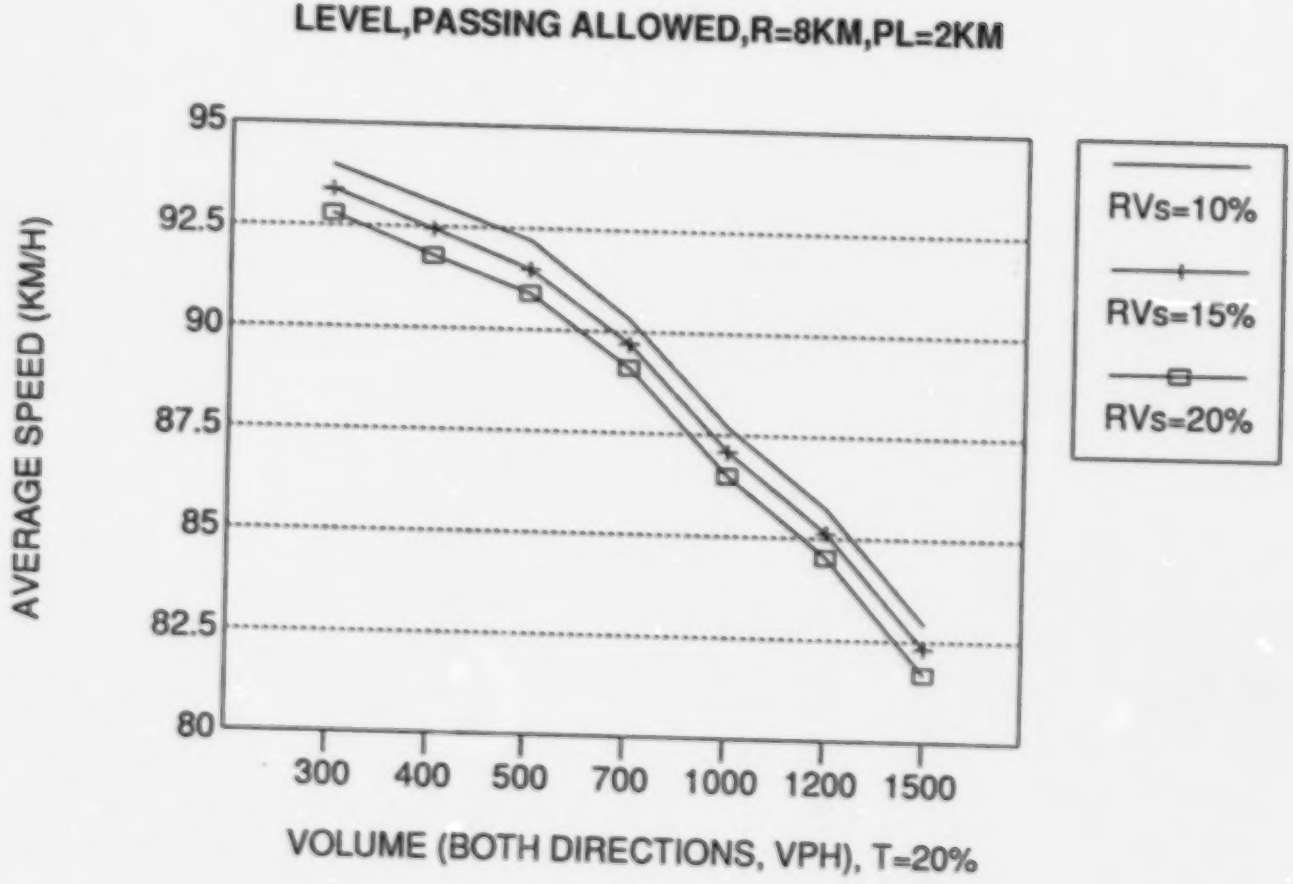


FIG.A.18: AVG. SPEED (BOTH DIRECTIONS)

LEVEL,PASSING ALLOWED,R=8KM,PL=2KM

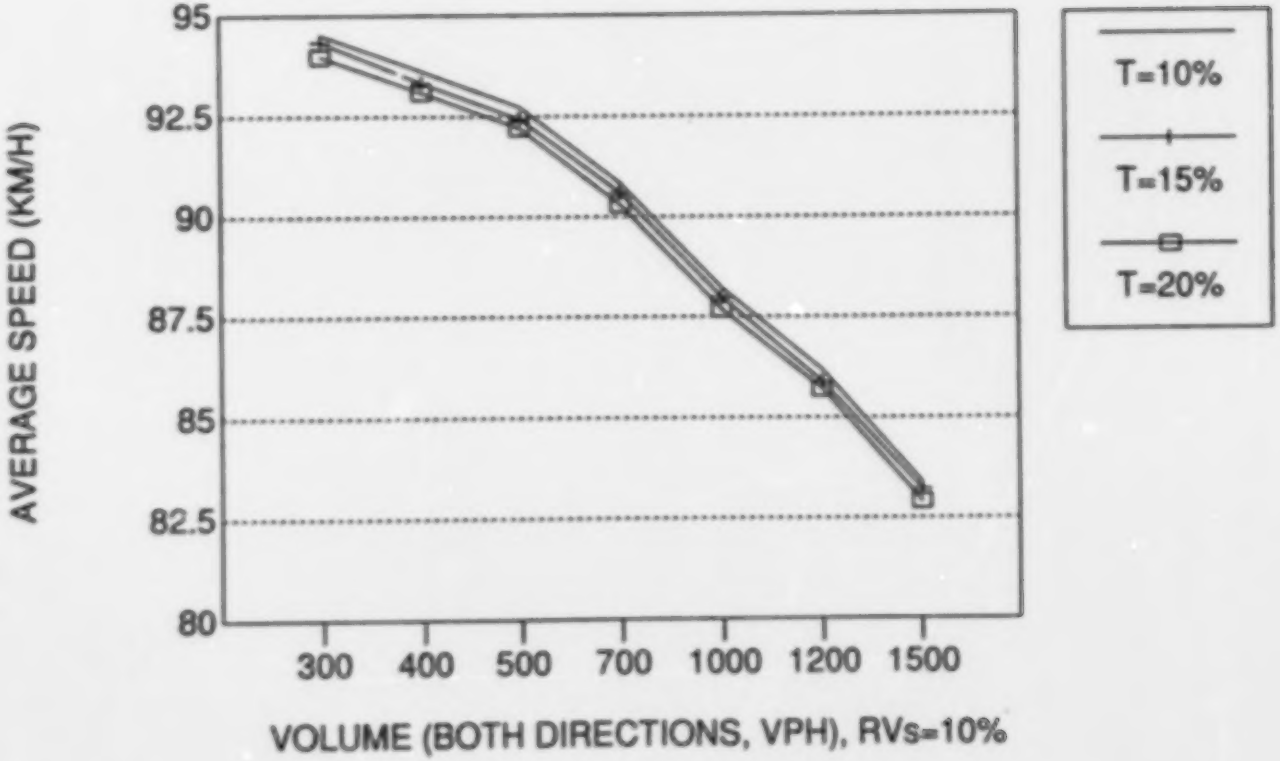


FIG.A.19: AVG. SPEED (BOTH DIRECTIONS)

LEVEL,PASSING ALLOWED,R=8KM,PL=2KM

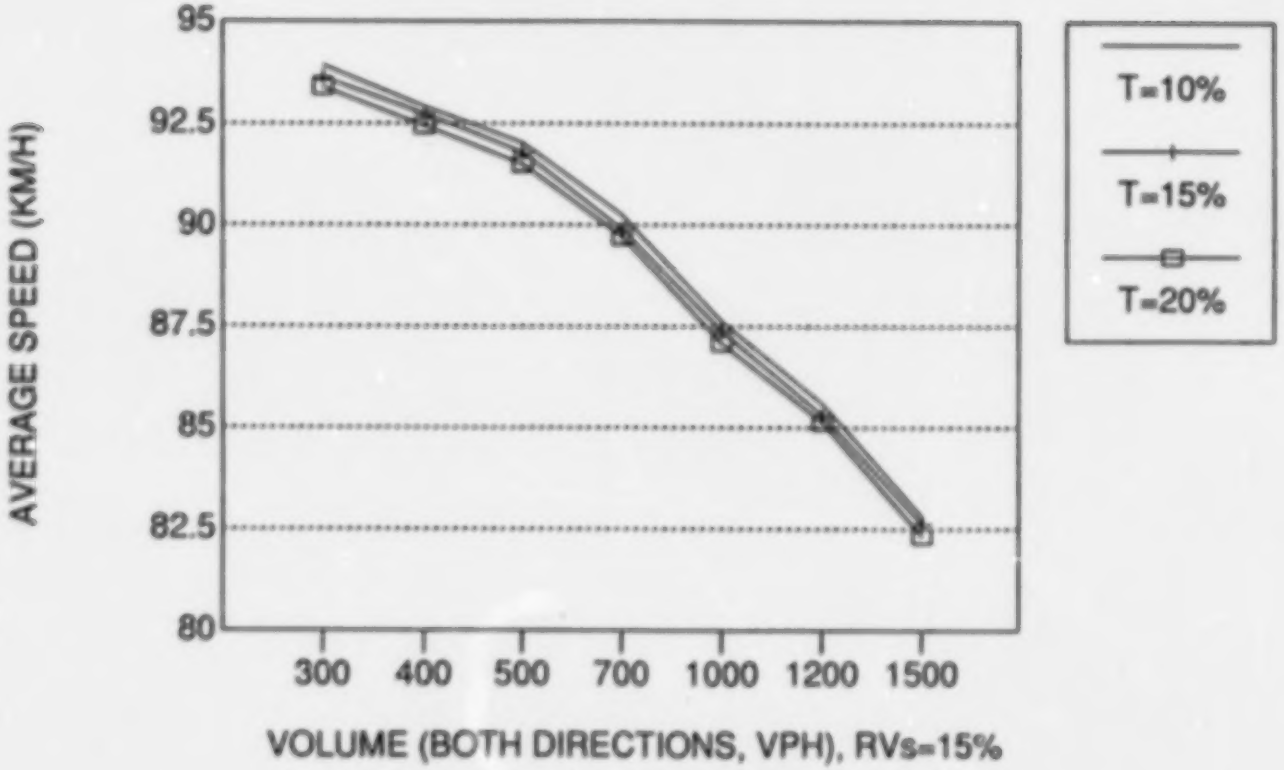


FIG.A.20: AVG. SPEED (BOTH DIRECTIONS)

LEVEL,PASSING ALLOWED,R=8KM,PL=2KM

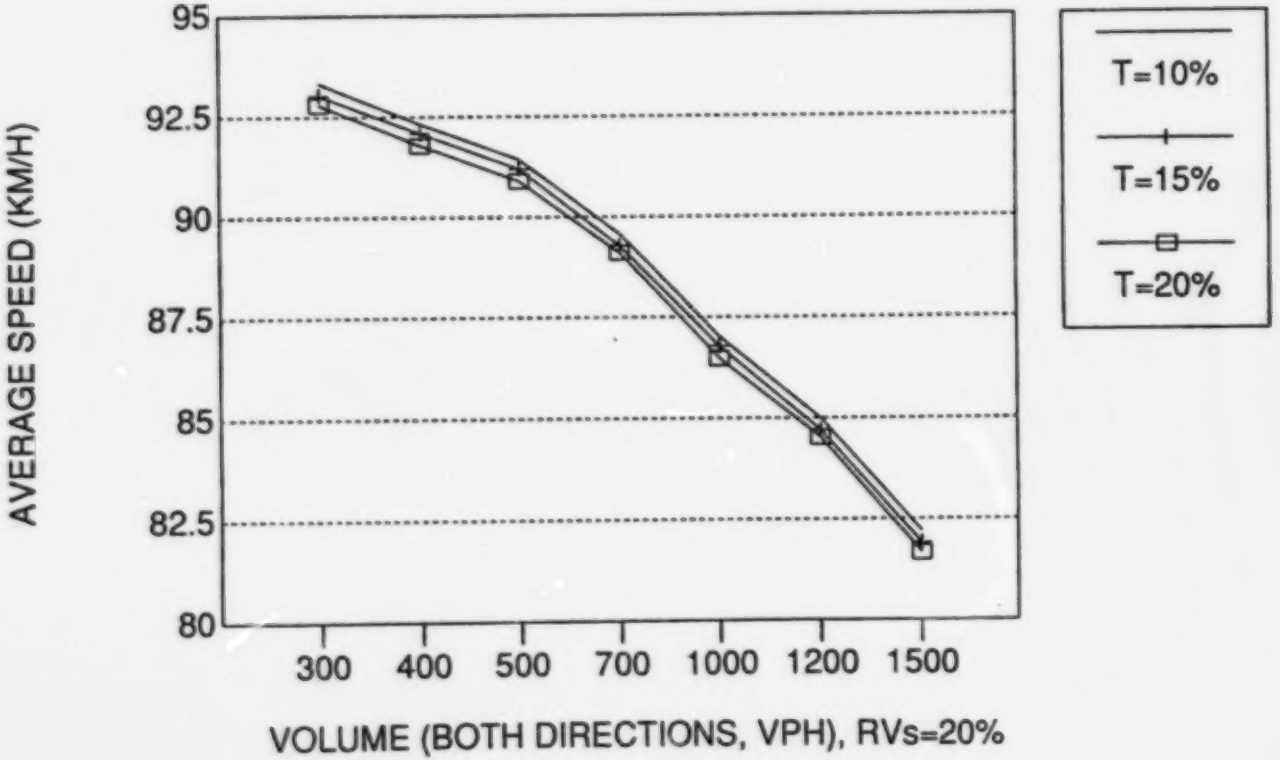


FIG.A.21: AVG. SPEED (BOTH DIRECTIONS)

ROLLING,PASSING ALLOWED,R=8KM,PL=2KM

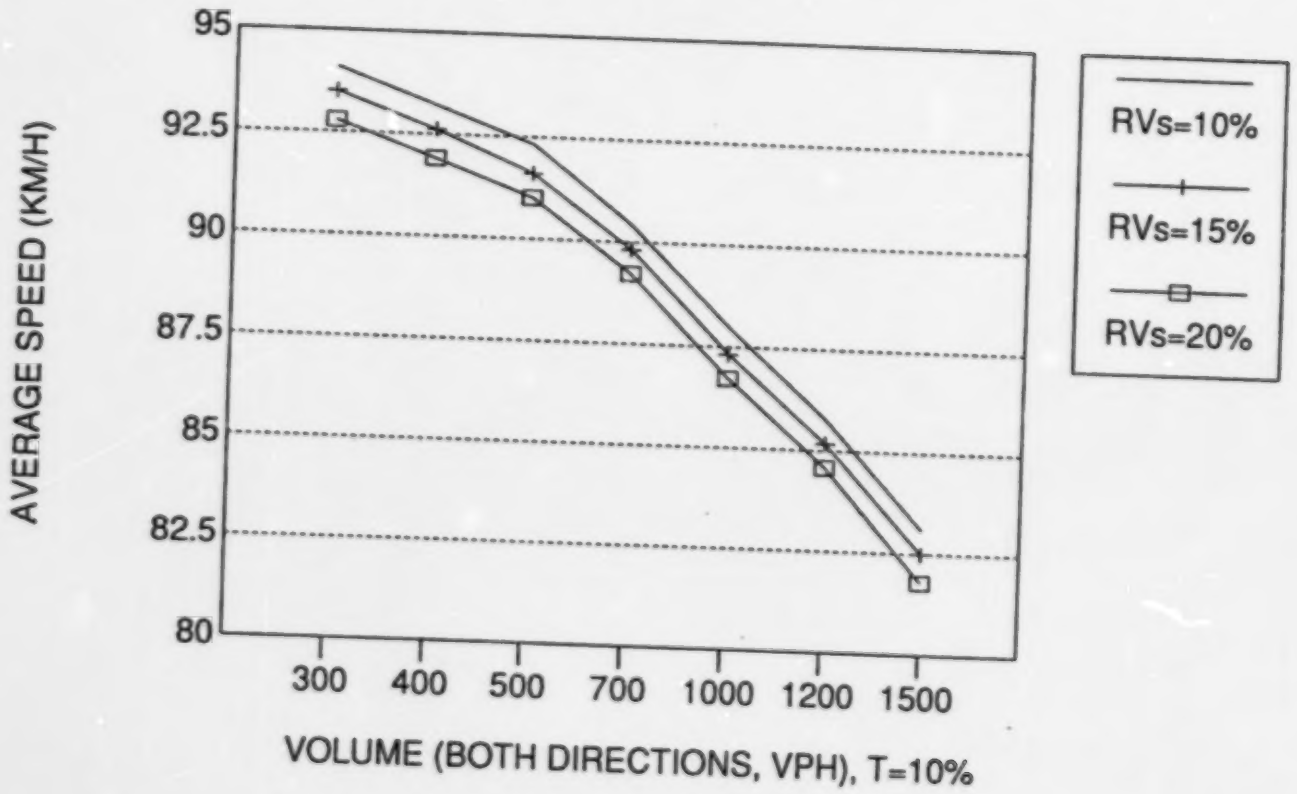


FIG.A.22: AVG. SPEED (BOTH DIRECTIONS)

ROLLING,PASSING ALLOWED,R=8KM,PL=2KM

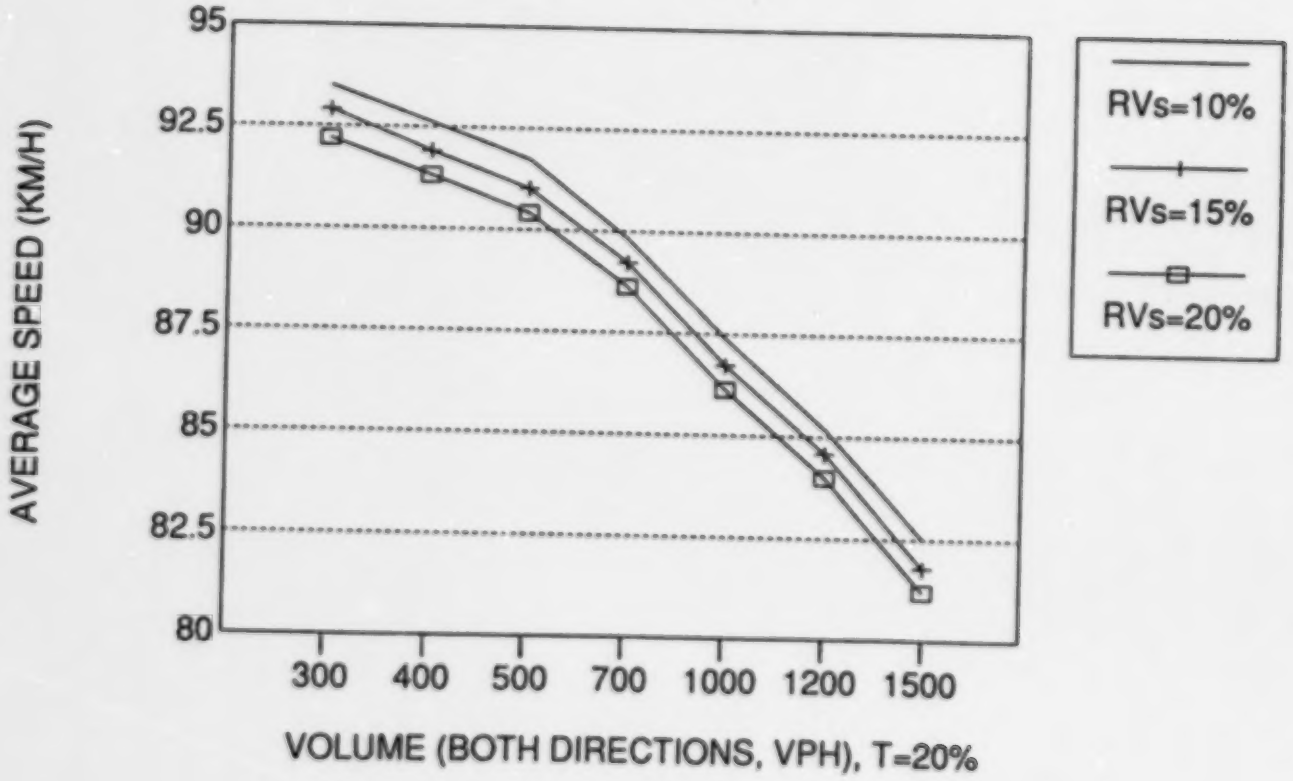


FIG.A.23: AVG. SPEED (BOTH DIRECTIONS)

ROLLING,50% PASSING ZONE,R=8KM,PL=2KM

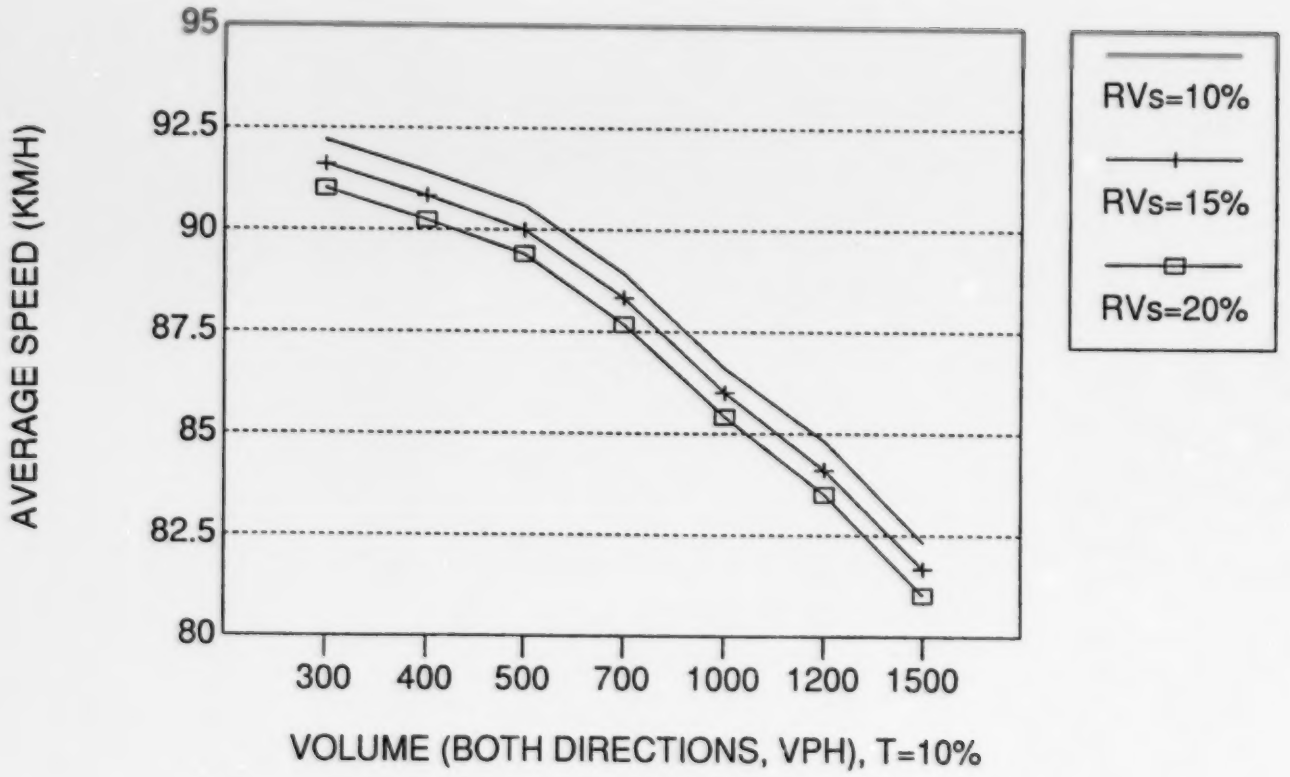
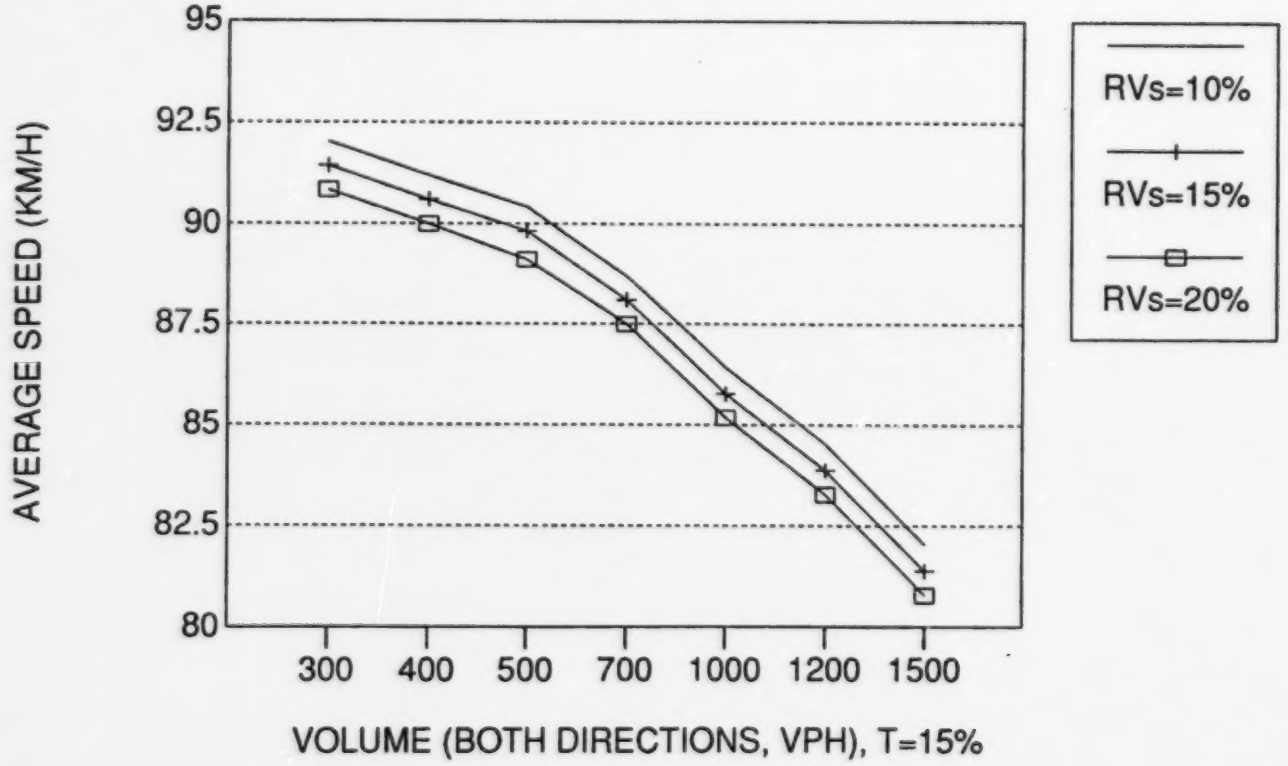


FIG.A.24: AVG. SPEED (BOTH DIRECTIONS)

ROLLING,50% PASSING ZONE,R=8KM,PL=2KM